FINAL REPORT

EVALUATION OF RAINFALL/RUNOFF PATTERNS IN THE UPPER COLORADO RIVER BASIN

report to

Texas Water Development Board

TWDB Contract No. 1600012011

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Pursuant to House Bill 1 as approved by the 84th Texas Legislature, this study report was funded for the purpose of studying environmental flow needs for Texas rivers and estuaries as part of the Adaptive Management Phase of the Senate Bill 3 Process for Environmental Flows established by the 80th Texas Legislature. The views and conclusions expressed herein are those of the author(s) and not do not necessarily reflect the views the of the Texas Water Development Board.

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EXECUTIVE SUMMARY

The analyses performed herein were undertaken to explore whether recent observed flows in the Colorado River basin upstream of the Highland Lakes are in fact substantially lower than what has been observed historically, and if so, to determine the likely reasons for the disparity. Pursuant to the scope of work and the BBASC's proposed approach for addressing this issue, this work has involved the review of long term (1940-2016) rainfall-runoff patterns in the Upper Colorado Basin by analyzing data for 14 watersheds upstream of streamflow gages in the study area, 10 of which represent most of the major tributaries of the Colorado River with the other 4 sites located on the mainstem of the river itself.

Observed flows and precipitation were compiled from available sources, and observed precipitation information was evaluated on a monthly and seasonal basis to determine if long term trends appear to have changed. Results show that while there are some changes over the period of record for some of the information reviewed, long term precipitation volumes at all of the study sites generally indicate a steady to slightly increasing trend over the 1940-2016 study period.

Observed flows were compiled for each of the study sites, and TCEQ's naturalized flows were extracted from the model input files for the Colorado Basin Water Availability Model. Corresponding sets of these flows were used to quantify the extent observed flows may have been historically impacted by streamflow depletions caused by existing appropriative water rights. Comparisons were made of observed precipitation, observed flow, and naturalized flow for each of the study sites. Results from these comparisons indicate that while observed precipitation has been generally steady, observed flow trends at all sites have declined over the period. Analysis of the naturalized flow information indicates that most of the declining trend of observed flows for the majority of the study sites can be attributed to historical water use and the construction of large reservoirs upstream, both of which are associated with existing water rights of record in the study area. However, for several of the study sites, it appears that the declines in observed flows were not the result of flow depletions by upstream permitted water rights since few, if any, authorized water rights are authorized upstream. Furthermore, all sites demonstrated some degree of decline in naturalized flows over the period of record, indicating that activities not accounted for in the flow naturalization process could have impacted observed flows, to some degree, over the period of record.

A list also was developed of other activities that could have impacted the observed flows over time that are not accounted for in the naturalized flow database. Several of these activities were investigated, with the following four believed to have had some impact on the trend of observed and naturalized flows over the study period:

(1) The proliferation of noxious brush.
(2) The construction of small reservoirs, not accounted for in naturalized flows.
(3) Groundwater use and aquifer water level declines.
(4) Changes in average temperatures and drought conditions.

A limited review of these activities was made and available information was compiled and analyzed. Each of these activities and their possible impacts on observed and naturalized flows are discussed below.

<u>Noxious Brush</u>

Almost all of the study sites are believed to have some degree of noxious brush problems in their contributing watersheds; however, study sites #1, #2, and #3 have had numerous feasibility studies conducted and published that estimate large quantities of streamflow could be recovered if various levels of brush control were implemented. In particular, the North Concho Brush Control Project was completed in the watershed of study site #1, with approximately 340,000 acres of ash juniper and honey mesquite being removed by about 2011. Many experts disagree about the success of substantially increasing flows on a watershed scale by removing brush, and monitoring information after this project was completed only show small gains in streamflow and groundwater elevations. However, several of the years since the project was completed experienced low rainfall, possibly contributing to the inconclusive results and the feasibility reports for this project indicated that that aquifers in the area would need to recover substantially before the predicted increases in surface water flow would be realized. The acreage of noxious brush that has been removed from this watershed is significant, amounting to approximately 40% of the total watershed area of the North Concho River. Consequently, the question of whether brush control of this magnitude can substantially increase flow on a watershed basis will likely have to be answered in the coming years, as more data become available to facilitate comparison of observed flows before and after this brush control project was implemented.

<u>Small Reservoirs</u>

Only historical depletions by major reservoirs and diversions for all other appropriative water rights are accounted for in the naturalized flow process. Therefore, at least part of the unexplained decline in naturalized flows certainly could be related to flow impoundments by small ponds and reservoirs, which includes reservoirs that exist under both appropriative and exempt water rights. Since the historical impoundment quantities of these small ponds and reservoirs were not accounted for when the naturalized flows were developed, the impacts of these small ponds and reservoirs are imbedded in the naturalized flows after the reservoirs were constructed but they are not reflected in the earlier periods before the reservoirs were constructed, thus the naturalized flows may not be reasonably comparable before and after these reservoirs were constructed. Two different data sources were reviewed that enable some quantification of these small reservoirs, and efforts were conducted to determine the combined quantity of storage, or water surface area, attributable to these smaller reservoirs. In addition, an analysis was conducted for one of the study sites in an attempt to quantify the extent many of these unaccounted-for small impoundments could have caused the naturalized flows in the later period to be lower than those for the earlier period. The results from these analyses and other published information reviewed suggest that the cumulative effects of numerous small reservoirs in the watersheds upstream of the study sites have impacted the observed and naturalized flows to some degree. However, the body of information available to quantify all of these small reservoirs' location, size and date of completion is very limited and is not sufficient to fully address this issue.

It should be noted that the Colorado River Basin, particularly in the study area of this project, is recognized as being very limited with regard to water being available for appropriation for new water rights. Therefore, it is unlikely there will be many, if any, new water rights granted in the Colorado River Basin in the future, which of course means that the opportunity to construct new small reservoirs subject to the water rights permitting process is likewise very limited. However, there are no such permitting constraints on the construction of exempt reservoirs; thus, it is likely additional exempt reservoirs will continue to be constructed in the watersheds of the study area. In addition, information related to land use changes in the study area indicate an increasing trend of larger parcels of land being subdivided and sold as multiple smaller tracts of land. This change may contribute to even more construction of small ponds and reservoirs in the future.

Groundwater Declines

Information from TWDB's monitoring well information was reviewed for most of the counties upstream of each study site. Time series plots of groundwater level variations for numerous wells completed in different aquifers were created and reviewed, and aquifers that had observation wells showing declining elevations over the period of record were noted. Most of the study sites showed some amount of groundwater decline associated with aquifers lying within their watersheds. Published information for the aquifers that were identified with declines was reviewed to better understand the significance of the declines. In some cases, the published information indicated that there are known interactions between aquifers and surface water bodies in the area. However, in most other cases, the published aquifer information did not specifically address whether such interactions exist or not. Therefore, the extent the declining trends in observed and naturalized flows can be attributed to aquifer water level declines cannot be estimated.

Historical Temperature Changes and Drought Conditions

Review of historical temperature information for two stations that contain long term observations indicate that average temperatures have been steadily increasing over much of the period of record of this study. Similarly, examination of NOAA's Palmer Drought Severity Index (PDSI) for the Edwards Plateau climatic district, which covers most of the study area, also suggests that the recent drought conditions experienced in 2011 were the most severe (though not the longest in duration) for the entire period of record. In addition, the PDSI information indicates that the period from about 1990 to 2014 has experienced more extreme wet/dry events. This information suggests that some portion of the declines in observed and naturalized flows during the late period of record may be related to the more extreme climatic conditions exhibited by these observations, which likely affected many other factors that influence the soil moisture and runoff that actually produces the observed flows at the study sites.

Finally, it should be noted that in all cases but one, the observed flows for last two years of the study period (2015-2016) show an increase in the trend of observed flows. Although the naturalized flow dataset is not yet available for these years, the fact that observed flows have increased will likely translate to an increase in the trend of naturalized flows as well. This increase suggests that many of the small decreases noted in the later years before 2015 for many of the study sites may have been related to the most recent severe drought, which began in many areas of the study area in 2007 and lasted until early 2015.

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1.0 PROJECT OVERVIEW

1.1 Statement of Problem and Study Objectives

Observed streamflows in the Colorado River basin upstream of the Highland Lakes have been noted to be lower in recent years than what has been observed in the past. Although this part of the Colorado River basin has suffered from a severe drought recently, historical flow quantities occurring over a long period of record have been questioned by the Texas Water Development Board (TWDB), Colorado and Lavaca Basin Bay Area Stakeholder Committee (BBASC), Colorado and Lavaca Basin Bay Expert Science Team (BBEST), and others. The purpose of this study is to explore whether recent flows are in fact substantially lower than what has been observed historically, and if so, determine the likely reasons for the disparity. The budget and associated scope of this project were tailored to make use of existing relevant information readily available from various sources and to assess the overall rainfall-runoff relationships at a limited number of key locations within a large study area in order to better understand the observed streamflow conditions occurring over time and the activities that are, or could be, impacting these flows.

1.2 Scope of Work

This research study has been undertaken by Kennedy Resource Company (KRC) under contract to the Texas Water Development Board (TWDB) and was authorized by the TWDB on July 21, 2016 pursuant to Contract No. 1600012011 between the TWDB and KRC. The effective Scope of Work controlling the terms and extent of the research is attached as Attachment A. Two subcontractors (R.J. Brandes Consulting and Crespo Consulting Company) were used as sub-consultants for various portions of the tasks associated with this research. The research for this study was in response to item #9 identified in the BBASC's work plan dated June 26, 2012, which summarized the issue to be analyzed as follows:

> **"Evaluate decline in flows in upper Colorado Basin with particular emphasis on understanding the apparent change in relationship between rainfall and river flow.**
>
> **Coordinating agency: TWDB**
>
> *This task will initially involve evaluations of the relationship between rainfall and river and stream flow over time in order to gain a better understanding of how that relationship may have changed over the period for which records are available. Based on that improved understanding, the next phase is intended to help identify potential causes in that relationship. It may be appropriate to involve regional experts with knowledge of flows and changes that have occurred over time in the area.*

1.3 Study Area

The study area for this analysis is called the Upper Colorado River Basin, which is defined as the Colorado River basin upstream of Buchanan and Travis Reservoirs, also known as the Highland

Lakes. The Colorado Basin upstream of these reservoirs encompasses a large part of the state, with the most upstream area of the basin essentially beginning in New Mexico. Figure 1A shows the extent of the study area with the streamflow gaging stations used in this study indicated, along with major cities and county lines displayed. There are 49 counties that have some portion of their boundary within this portion of the Colorado Basin in Texas, with 26 counties being located in the major watershed area of the study area, which will be defined in the coming sections. Figure 1B shows the same extent of the study area but displays the WAM subwatershed identifiers, which will be defined later in this chapter.

1.4 Overview of Study Approach

This study involves the review of relevant observed historical records to determine the extent observed streamflows have changed over a long period of time. The period 1940-2016 was selected as the desired period of record to analyze. This period was selected because (1) this 77 year period encompasses a wide variety of hydrologic and climatic conditions, including the drought of the 1950's, as well as numerous more recent drought periods including the most recent drought period that began in about 2007 in most of the study area, (2) several of the study sites had observed flows for the entire period, and (3) this period is generally consistent with the common period used for most water rights/water supply analysis throughout the state. A group of United States Geological Survey (USGS) gaging stations were selected that represent the various major tributaries to the Colorado River, as well as several sites on the main stem of the Colorado River throughout the study area. Observed streamflow records were reviewed for each of these sites and other information such as precipitation, groundwater elevation, groundwater use, and land use information were also analyzed in an attempt to understand the variations of observed flow seen at the selected sites. The Texas Commission on Environmental Quality's (TCEQ) naturalized flows were also obtained and used extensively to quantify the extent the activities of existing known water users may have impacted flows observed at the gage sites. Numerous comparisons were made of all of the various information to gain insight to changes in observed flows over time. This resulted in numerous complex charts and tables of information that must be viewed in order to understand the basis for several of the conclusions herein. Most of these graphics are in appendices at the end of this report, with several of the most important appendices containing 14 pages (one for each study site) so that the reader can easily view the same comparison logic for each study site. All of these appendices are introduced in the first four chapters of the report, then relied on to generalize the detailed observations of each study site in Chapter 5.

Figure 1A

Upper Colorado basin study area showing major subwatersheds, county lines, major cities, and spring locations

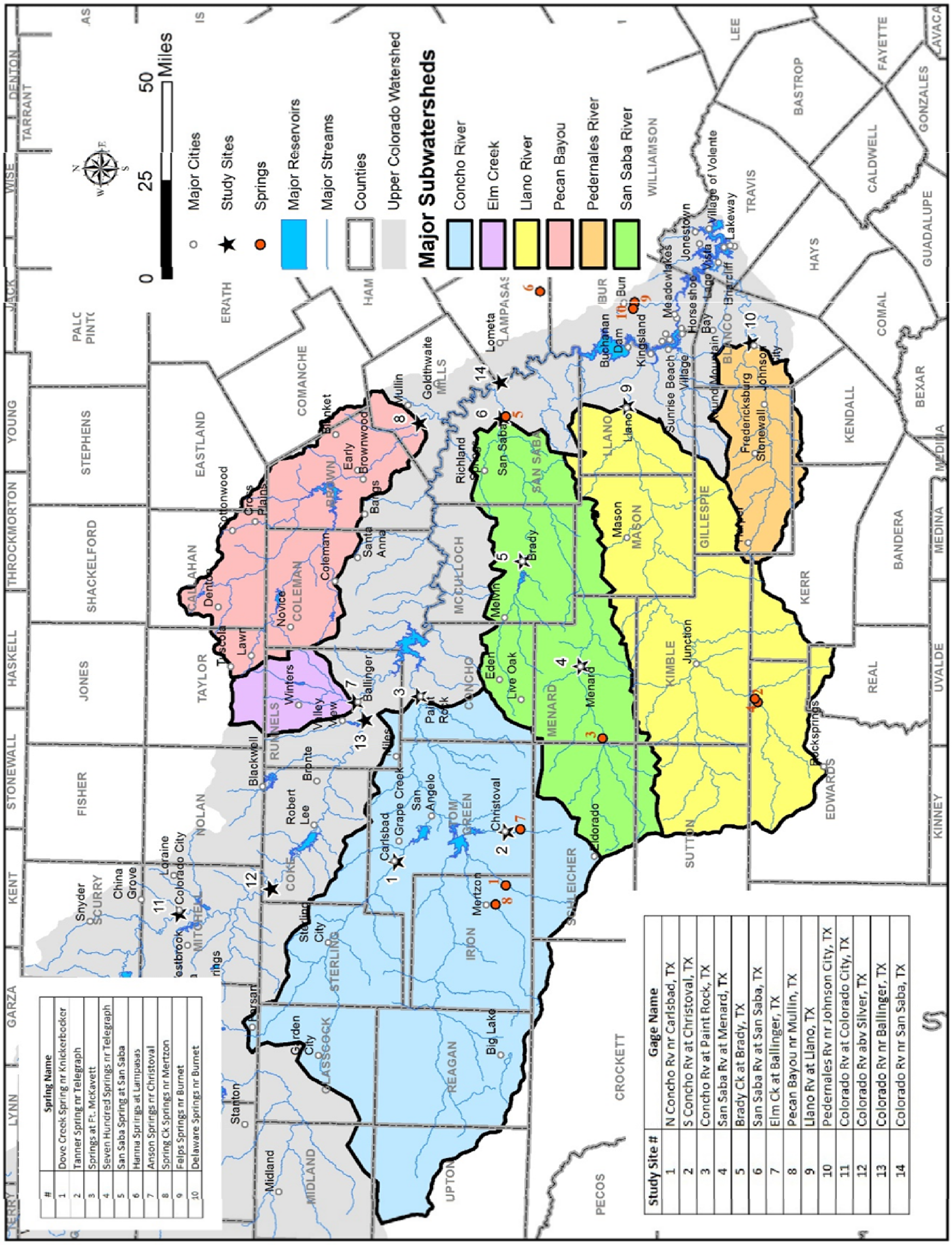
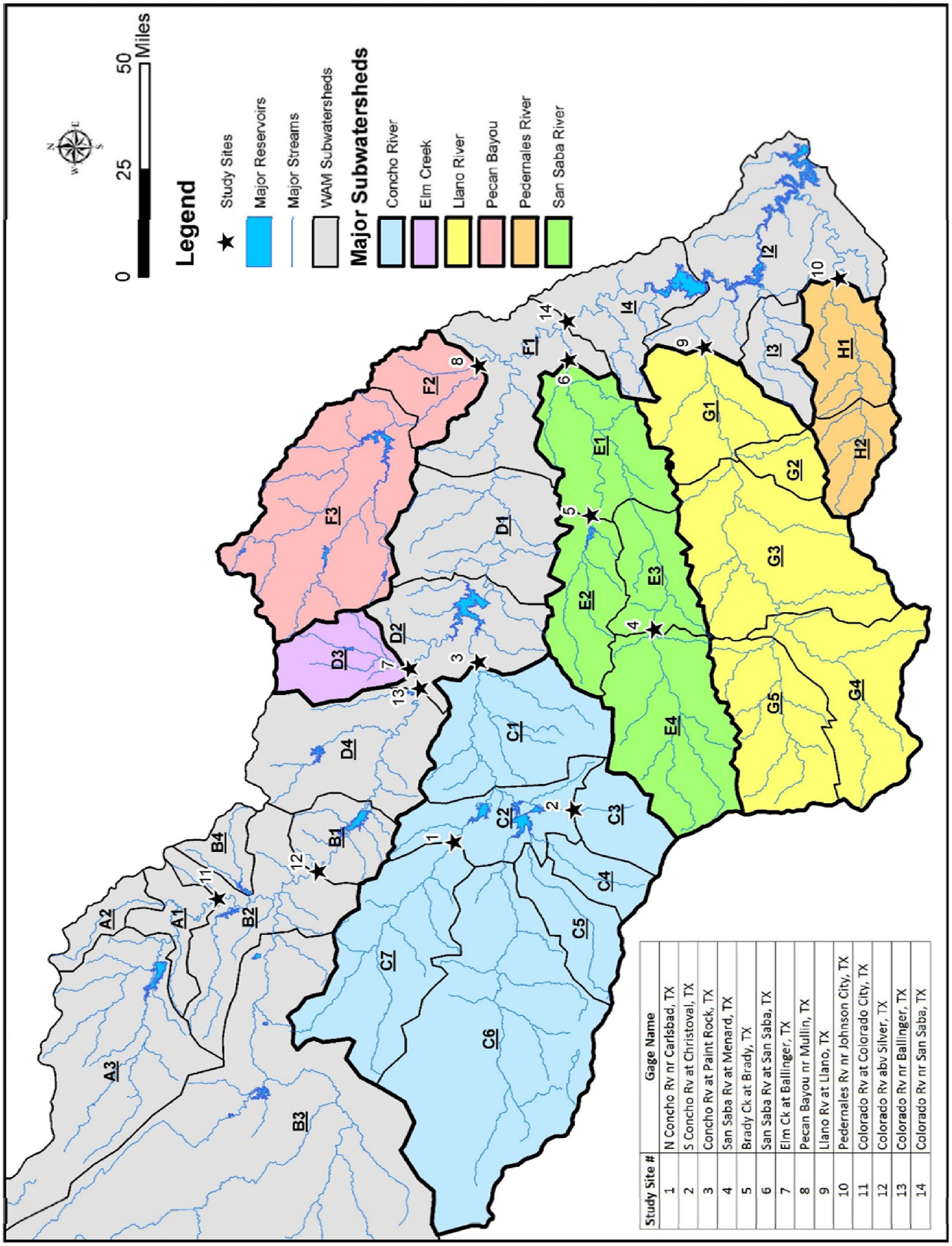


Figure 1B

Upper Colorado basin study area showing major subwatersheds

and WAM subwatershed identifiers



1.5 Watersheds in Study Area and Organization of Information

The TCEQ's maintains a water availability model (WAM) representing the entire Colorado River Basin, which is primarily used to provide water availability information necessary for the TCEQ's task of reviewing new water right applications and amendment applications for existing water rights. As part of the WAM development, the TCEQ created a naming convention and associated it to all of the USGS gaging station locations used in the WAM model. Since this organization was already in place and provides a logical approach to organizing and comparing the various results throughout the basin, these naming conventions and organization structure were adopted for this study. Table 1 presents the structure details and naming conventions used in the TCEQ WAM model for all locations in the Upper Colorado River Basin. The field identified as "WAM subwatershed" in column 3 contains the identifier used in the TCEQ's WAM model to designate the geographic extent of a subwatershed within the larger WAM model. These subwatershed identifiers are also indicated in bold underline in the study area map previously introduced as Figure 1B and will be used throughout the report to quantify various activities that are discussed and analyzed.

Table 1
Streamflow gages used in TCEQ WAM in upper Colorado Basin

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ROW #	STUDY SITE NUMBER	PER TCEQ WAM MODEL STRUCTURE						
		WAM SUB WATERSHED	DESCRIPTION	USGS #	TOTAL DRAINAGE AREA (SM)	WAM SUB WATERSHEDS AT AND UPSTREAM	INCREMENTAL WATERSHED CALCULATION GUIDE	INCREMENTAL DRAINAGE AREA (SM)
(1)		A3	Colorado R nr Ira	08119500	1,074	A3	-	-
(2)		A2	Deep Ck nr Dunn	08120500	193	A2	-	-
(3)	11	A1	Colorado R at Colorado City	08121000	1,575	A1,A2,A3	-A2-A3	308
(4)		B4	Champion Ck Reservoir	08123600	176	B4	-	-
(5)		B3	Beals Ck nr Westbrook	08123800	1,974	B3	-	-
(6)	12	B2	Colorado R abv Silver	08123850	4,559	B4,B3,B2,A1,A2,A3	-B4-B3-A1	1,336
(7)		B1	Colorado R at Robert Lee	08124000	5,046	B4,B3,B2,B1,A1,A2,A3	-B2	487
(8)	1	C7	North Concho R nr Carlsbad	08134000	1,202	C7	-	-
(9)		C6	Middle Concho R abv Tankersley	08128400	1,613	C6	-	-
(10)		C5	Spring Ck abv Tankersley	08129300	340	C5	-	-
(11)		C4	Dove Ck at Knickerbocker	08130500	164	C4	-	-
(12)	2	C3	South Concho R at Christoval	08128000	258	C3	-	-
(13)		C2	Concho R at San Angelo	08136000	4,139	C7,C6,C5,C4,C3,C2	-C3-C4-C5-C6-C7	562
(14)	3	C1	Concho R at Paint Rock	08136500	5,185	C7,C6,C5,C4,C3,C2,C1	-C2	1,046
(15)	13	D4	Colorado R nr Ballinger	08126380	6,090	D4,B4,B3,B2,B1,A1,A2,A3	-B1	1,044
(16)	7	D3	Elm Ck at Ballinger	08127000	464	D3	-	-
(17)		D2	Colorado R nr Stacy	08136700	12,548	D4,D3,D2,C7,C6,C5,C4,C3,C2,C1,B4,B3,B2,B1,A1,A2,A3	-C1-D4-D3	5,994
(18)		D1	Colorado R at Winchell	08138000	13,788	D4,D3,D2,D1,C7,C6,C5,C4,C3,C2,C1,B4,B3,B2,B1,A1,A2,A3	-D2	1,240
(19)	4	E4	San Saba R at Menard	08144500	1,137	E4	-	-
(20)		E3	San Saba R nr Brady	08144600	1,636	E3,E4	-E4	499
(21)	5	E2	Brady Ck at Brady	08145000	589	E2	-	-
(22)	6	E1	San Saba R at San Saba	08146000	3,048	E4,E3,E2,E1	-E3-E2	823
(23)		F3	Pecan Bayou at Brownwood	08143500	1,654	F3	-	-
(24)	8	F2	Pecan Bayou nr Mullin	08143600	2,074	F3,F2	-F3	420
(25)	14	F1	Colorado R nr San Saba	08147000	19,830	F3,F2,F1,E4,E3,E2,E1,D4,D3,D2,D1,C7,C6,C5,C4,C3,C2,C1,B4,B3,B2,B1,A1,A2,A3	-E1-D1-F2	3,968
(26)		G5	North Llano R nr Junction	08148500	897	G5	-	-
(27)		G4	Llano R nr Junction	08150000	1,859	G5,G4	-G5	962
(28)		G3	Llano R nr Mason	08150700	3,251	G5,G4,G3	-G4	1,392
(29)		G2	Beaver Ck nr Mason	08150800	215	G2	-	-
(30)	9	G1	Llano R at Llano	08151500	4,201	G5,G4,G3,G2,G1	-G3-G2	736
(31)		H2	Pedernales R nr Fredericksburg	08152900	370	H2	-	-
(32)	10	H1	Pedernales R nr Johnson City	08153500	901	H2,H1	-H2	531
(33)		I4	Lake Buchanan nr Burnet	08148000	20,521	I4,F3,F2,F1,E4,E3,E2,E1,D4,D3,D2,D1,C7,C6,C5,C4,C3,C2,C1,B4,B3,B2,B1,A1,A2,A3	-F1	691
(34)		I3	Sandy Ck nr Kingsland	08152000	346	I3	-	-
(35)		I2	Lake Travis nr Austin	08154500	27,357	H2,H1,I4,I3,I2,F3,F2,F1,E4,E3,E2,E1,D4,D3,D2,D1,C7,C6,C5,C4,C3,C2,C1,B4,B3,B2,B1,A1,A2,A3	-I3-G1-H1-I4	1,388

1.6 Sites Selected for Study (Study Sites)

A list of all gaging stations was obtained from the USGS for which observed flows have been published in the study area. From this list, 14 sites were selected as suitable study sites for this analysis, all of which either have at least 45 years of observed flow information, or were sites the BBASC made environmental flow recommendations for pursuant to Senate Bill 3. Table 2 lists the 14 locations used in this analysis along with the counties that are associated with the majority of the contributing watershed upstream of the selected study sites.

Table 2
USGS gaging stations selected as study sites

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	STUDY SITE WATERSHED INFORMATION						
	STUDY SITE NUMBER	WAM SUB WATERSHED	STATION_NM	USGS NUMBER	RECORD OF OBSERVED FLOW	Study Sites Located Upstream	ASSOCIATED COUNTIES (1)
(1)	1	C7	N Concho Rv nr Carlsbad, TX	08134000	1/1940-12/2016	None	Sterling, Glasscock, Tom Green, Coke
(2)	2	C3	S Concho Rv at Christoval, TX	08128000	1/1940-9/1995; 5/2001-12/2016	None	Tom Green, Schleicher
(3)	3	C1	Concho Rv at Paint Rock, TX	08136500	1/1940-12/2016	1,2	Tom Green, Concho, Runnels
(4)	4	E4	San Saba Rv at Menard, TX	08144500	1/1940-9/1993; 10/1997-12/2016	None	Menard, Schleicher
(5)	5	E2	Brady Ck at Brady, TX	08145000	1/1940-9/1986; 4/2001-12/2016	None	McCulluch, Concho, Menard
(6)	6	E1	San Saba Rv at San Saba, TX	08146000	1/1940-9/1993; 10/1997-12/2016	4,5	San Saba, McCulluch, Mason
(7)	7	D3	Elm Ck at Ballinger, TX	08127000	1/1940-12/2016	None	Runnels, Taylor
(8)	8	F2	Pecan Bayou nr Mullin, TX	08143600	10/1967-12/2016	None	Mills, Brown
(9)	9	G1	Llano Rv at Llano, TX	08151500	1/1940-12/2016	None	Llano, Mason, Gillespie
(10)	10	H1	Pedernales Rv nr Johnson City, TX	08153500	1/1940-12/2016	None	Gillespie, Blanco
(11)	11	A1	Colorado Rv at Colorado City, TX	08121000	6/1946-12/2016	None	Mitchell, Howard, Borden, Scurry
(12)	12	B2	Colorado Rv abv Silver, TX	08123850	9-1967-12/2016	11	Mitchell, Scurry, Coke, Nolan
(13)	13	D4	Colorado Rv nr Ballinger, TX	08126380	1/1940-12/2016	11,12	Runnels, Coke, Nolan, Taylor
(14)	14	F1	Colorado Rv nr San Saba, TX	08147000	1/1940-12/2016	1,2,3,4,5,6,7,8, 11,12,13	Brown, Mills, San Saba, McCulluch

(1) The counties listed are the counties that dominate most of the nearby watershed upstream of each study site but do not necessarily include all counties upstream.

For purposes of this analysis, the 14 study sites can be organized into the following groups:

(1) GROUP 1: Concho Watershed (Study Sites 1,2,3)
(2) GROUP 2: San Saba Watershed (Study Sites 4,5,6)
(3) GROUP 3: Elm Creek and Pecan Bayou Watersheds (Study Sites 7, 8)
(4) GROUP 4: Llano and Pedernales Watersheds (Study Sites 9, 10)

(5) GROUP 5: Mainstem Colorado River Sites (Study Sites 11, 12, 13, 14).

As indicated above, 10 of the study sites selected represent locations on most of the major tributaries of the Colorado River in the study area and 4 sites are located on the main stem of the Colorado River. It should be noted that because of the upstream to downstream order of these groups and the commonality of sites within each group, many of the results and concluding observations made in Chapter 5 use this order to summarize findings.

1.7 Authorized Water Rights

A Geographic Information System (GIS) coverage was obtained from the TCEQ which depicts the locations of all water rights of record in the basin. Using this information along with information from the TCEQ's Colorado WAM connectivity structure and the TCEQ's water rights Masterfile, the total number of water rights in the study area was determined to be 1,113, which authorize 25 large reservoirs, described herein as "major reservoirs" and 324 small reservoirs (not counting off-channel reservoirs). The major reservoirs are loosely defined as having a substantial authorized capacity (on the order of at least 5,000 acre-feet or more) and are usually owned and operated by large water supply entities or cities. Because of the size and use of these reservoirs, most have a fair amount of information available related to their effective storage capacity, year built, etc. In addition to major reservoirs, many of the smaller water rights authorized to use water in the Colorado River basin are also authorized to impound flows in smaller reservoirs to increase their reliability of water use. Most of these reservoirs are owned by small farming, industrial, municipal or recreational interests and little if any information is known about them other than their authorized parameters.

All of the above water rights are called "appropriative water rights" because these water rights have been appropriated a certain volume of water by the State, based on either information submitted by the water right owner at some point in the past, or as a result of the State's adjudication of water rights completed in the 1980's. As a result of being granted an appropriative water right under the Texas Water Code, each of these water rights has a priority date assigned to its use and storage of water, which establishes its priority of use with respect to other appropriative water rights. In addition, each of these water rights is required to file a water use report, on a real time basis if located in the Concho Watermaster area, or every year in all other areas, to document the quantity of water actually diverted and used. Table 3 contains a list of the major reservoirs and their WAM subwatershed identifiers. Note that information relating which major reservoirs are located upstream of individual study sites will be detailed later in the report. Table 4 contains a list showing the total number of small reservoirs authorized and their combined authorized capacity for each WAM subwatershed. This information was tabulated by comparing information in TCEQ's water rights permitting version of the Colorado WAM data input files with TCEQ's Water Rights GIS coverage and water rights Masterfile database. More discussion on small reservoirs will be presented in Chapter 3.

Table 3
Major reservoirs in upper Colorado Basin (by year closed)

(1) WAM SWS	(2) MAJOR RESERVOIR	(3) YEAR CLOSED	(4) AUTHORIZED CAPACITY (AF)	(5) WATER COURSE
C2	Nazworthy	1930	12,500	South Concho
F3	Brownwood	1933	135,953	Pecan Bayou
I2	Inks	1938	17,545	Colorado River
I4	Buchanan	1938	992,475	Colorado River
I2	Travis	1942	1,170,752	Colorado River
D3	Old Winters	1945	not clear	Elm Creek
D4	Old Ballinger	1947	not clear	Valley Creek
F3	Hords Creek	1948	7,959	Hords Creek
B2	Colorado City	1949	29,934	Morgan Creek
D4	Oak Creek	1950	39,360	Oak Creek
I2	LBJ	1951	138,500	Colorado River
I2	Marble Falls	1951	8,760	Colorado River
A3	J.B.Thomas	1952	204,000	Colorado River
C2	O.C.Fisher	1952	119,200	North Concho River
B3	Natural Dam Lake	1957	54,560	Sulphur Springs Draw
B4	Champion Creek	1959	42,500	Champion Creek
C2	Twin Buttes	1963	186,200	South Concho River
E2	Brady	1963	30,000	Brady Creek
F3	Coleman	1966	40,000	Jim Ned Creek
B1	E.V.Spence	1969	488,760	Colorado River
F3	Clyde	1970	5,748	N Prong Pecan Bayou
D3	New Winters	1983	8,334	Elm Creek
B3	Red Draw	1985	9,150	Red Draw
D4	New Ballinger	1985	6,050	Valley Creek
D2	O.H.Ivie	1989	554,340	Colorado River
B3	Mitchell County	1991	27,266	Tributary of Beals Creek
B3	Sulphur Draw	1993	7,997	Sulphur Springs Draw

Table 4
Small reservoirs in upper Colorado Basin
Authorized under appropriative water rights system

(1) WAM SUBWATERSHED	(2) TOTAL NUMBER OF SMALL RESERVOIRS	(3) COMBINED AUTHORIZED CAPACITY (AF)
A3	3	883
A2	5	101
A1	0	0
B4	1	15
B3	8	6,635
B2	0	0
B1	0	0
C7	2	51
C6	0	0
C5	9	765
C4	2	111
C3	3	87
C2	13	2,878
C1	20	3,135
D4	16	3,385
D3	14	531
D2	7	1,000
D1	11	605
E4	7	562
E3	4	107
E2	3	420
E1	5	599
F3	34	6,918
F2	22	2,126
F1	25	3,200
G5	10	156
G4	11	389
G3	7	97
G2	2	7
G1	15	1,444
H2	12	406
H1	19	709
I4	5	1,354
I3	7	256
I2	22	1,507
TOTAL FOR STUDY AREA	324	40,436

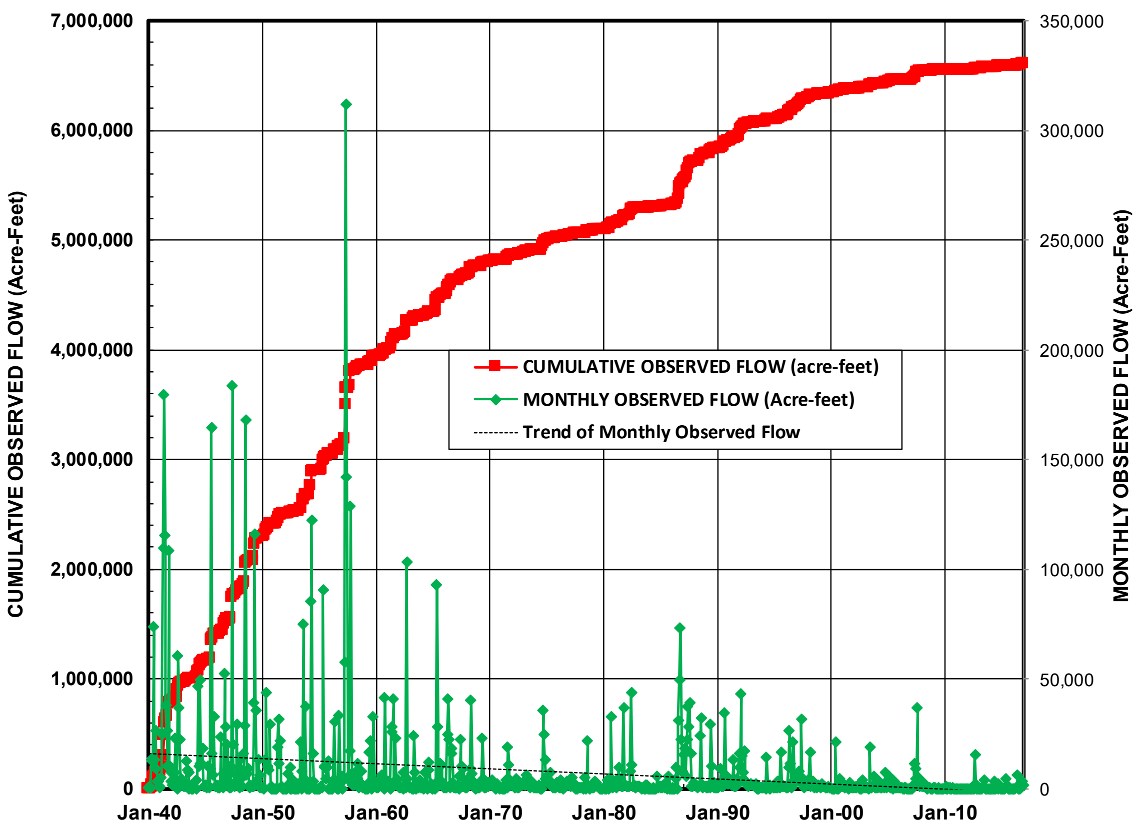
2.0 STEAMFLOW, PRECIPITATION, AND NATURALIZED FLOW

2.1 Observed Streamflow

Daily observed streamflow for each of the 14 sites in Table 2 were downloaded from the USGS for the period of record 1940-2016, to the extent records are available. As can be seen in Table 2, many of the study sites have continuous observed flow records while others are either missing periods within the study period or don't have any observations until well within the study period. The observed records were initially processed to determine the days within each record that had missing data and the remaining period was totaled into monthly and annual quantities. No attempt was made to fill in periods that were missing daily observed flow.

The resulting monthly quantities for each site were then accumulated for each month of the period of record, and the long term trend of the resulting cumulative flow was examined. All of the study sites were found to have some degree of declining trend in observed flow from the beginning to the end of the period of record. Figure 2 demonstrates this for study site # 13, Colorado River near Ballinger.

Figure 2
Observed flow for Colorado river near Ballinger



Note that both of the series displayed in Figure 2 contain the same monthly observed flow information for the 1940-2016 period, but are presented differently. The green diamond trace displays the actual monthly quantities with the black dashed line showing the trend of the monthly volumes, and the red squares display the accumulation of this information over time beginning in 1940. This figure demonstrates the trend of observed flows seen at many of the study sites analyzed, using both display techniques. The observed flow information for each of the study sites provides the foundation for the analysis in this study, and comparisons of these flows with precipitation and naturalized flows for each study site will be presented later in this section.

2.2 Precipitation

The National Centers for Environmental Information (NCEI) publishes observation records for many types of data for thousands of locations in the state, including daily precipitation information in the study area. A GIS coverage was created depicting the location of each NCEI precipitation station in the study area, and this coverage was reviewed in the general vicinity of each study site to understand what observed precipitation information was available.
. A list of attributes for all stations available in the study area was also obtained from the NCEI, which vaguely describes the period of record and "percent of period of record covered" by each station. Stations near each of the 14 study sites were tabulated and groups of candidate stations were selected and downloaded. The information was processed and reviewed to better understand the true extent of available observed precipitation. In several cases, sites were rejected because of too little valid observed data within the period of record, which required additional sites to be selected, downloaded, and the process repeated. Sites that had reasonable periods of record[1] and locations deemed to be reasonably near the streamflow study site were ultimately selected and downloaded. When multiple locations were available, preference was given to sites that were in or near the contributing watershed of the study site.

A spreadsheet process was developed that facilitated simultaneous review of numerous candidate stations for each day of the period of record. Beginning with 1/1/1940, the entire period of record through 12/31/2016 (28,125 days) was constructed using the observed precipitation for the NCEI station closest to the study site, to the extent it had observed information available. When a day was missing, the next closest NCEI station was used to fill in. In areas that had good observed precipitation data coverage, as little as three stations were all that were required to create a complete record. For other areas with sparse observed precipitation information, a larger radius from the study site had to be used in order to come up with the suitable candidates. Even after all of this effort, in some cases no daily observed precipitation records could be found within a

---

[1] The term "reasonable period of record" means precipitation stations that contained a substantial number of years of observed information. Precipitation stations that were either recently installed, or had a small percent of complete data for their period of record were prioritized last, in favor of selecting stations that had more observed information available.

reasonable distance from the study site. For these days, 0 was hand entered as the estimated precipitation. **Appendix A** shows the final NCEI stations that were used for each study site and includes the percent of days of the period of record each site was used to complete the record.

Considering the above described approach, the following two issues should be noted:

(1) The resulting composite precipitation record, at best, should be considered to be the historical observed precipitation in the vicinity of the study site, not at the exact location of the study site. This issue was recognized and thought to be reasonable since the ultimate plan was to relate this precipitation to monthly flow at the study gage, which by definition, represents conditions in the vicinity (i.e. upstream of the study site).

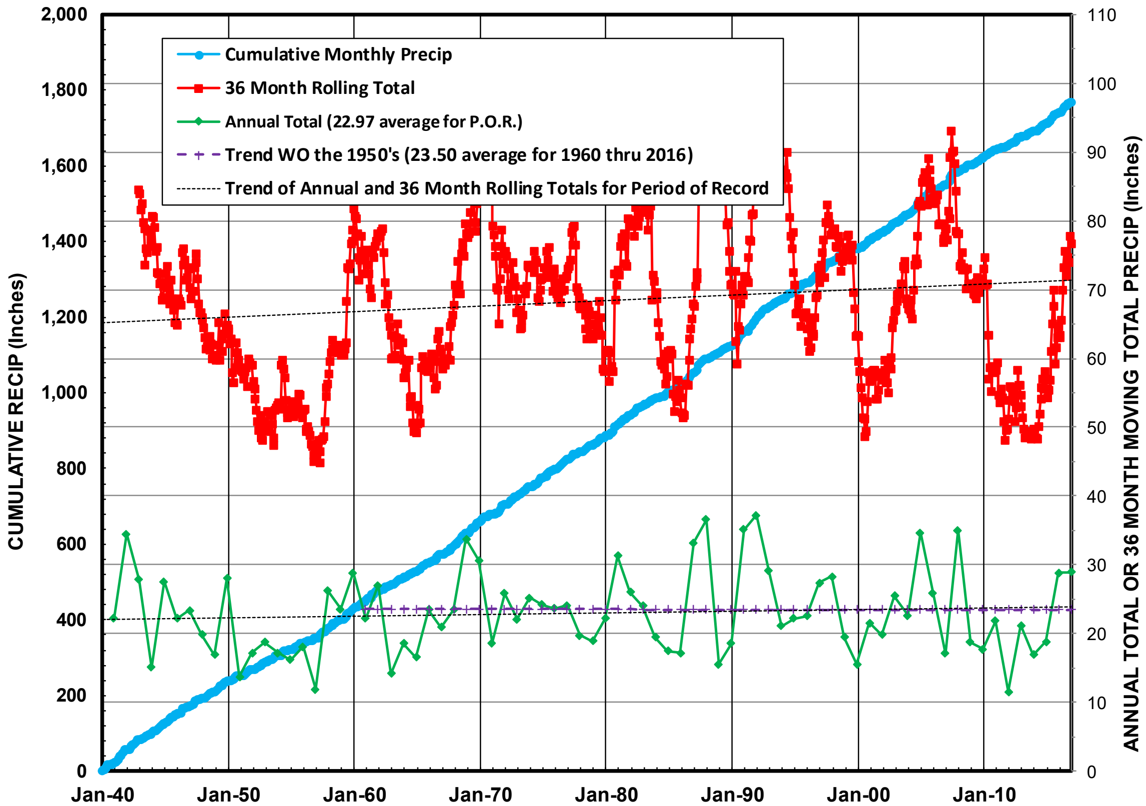
(2) It is unknown as to what extent the observed precipitation at a single location is representative of the precipitation occurring over the entire watershed. This is an uncertainty always inherent with observed precipitation information. It was concluded that the consideration of a long period of record should minimize this problem, but there is no way to completely remove this uncertainty.

The resulting monthly quantities of precipitation were analyzed numerous ways to be able to understand the extent that precipitation has or has not substantially changed over time. These analyses are described in the following sections.

2.2.1 Monthly Precipitation Analysis

Monthly volumes of precipitation quantities were accumulated for each month of the period of record and a 36 month running total was computed. This information was plotted for the entire period and is included as **Appendix B** for each of the 14 study sites. Figure 3 demonstrates this type of plot for study site # 13, Colorado River near Ballinger.

Figure 3
Monthly precipitation plot for study site #13
Colorado River near Ballinger



The information shown in Figure 3 (which also applies to the graphs presented in Appendix B for each of the study sites) is described below:

(1) The blue circles represent the cumulative monthly precipitation (left Y scale).
(2) The green diamonds represent the annual precipitation amounts with the annual average for the period of record stated in the plot legend. The dashed purple line with plus symbols shows the trend of annual precipitation if the period prior to 1960 is not considered and the annual average for the 1960-2016 period is also stated in the plot legend (right Y scale).
(3) The red squares represent the 36 month rolling total precipitation quantity (right Y scale).
(4) The dashed black line associated with items number 2 and 3 above show the full period of record trend of each quantity.

2.2.2 Seasonal Considerations

Monthly volumes of precipitation were also analyzed on a seasonal basis to determine if shifts have occurred between seasons within years. The seasonal definitions that were recommended by the BBEST and BBASC, and ultimately adopted by TCEQ, for this area of the Colorado River basin were used for this analysis. The months associated with each of the seasons are as follows:

- Spring: March, April, May, June
- Summer: July, August
- Fall: September, October
- Winter: November, December, January, February

The quantity of monthly precipitation occurring in each season of each year was computed and analyzed by counting the annual amount of precipitation occurring in each of the four seasons, as defined above. Table 5 summarizes the annual and monthly precipitation trend information discussed in the previous two sections.

Table 5
Precipitation summary at study site locations

STUDY SITE #	PRECIPITATION								
	ANNUAL			TREND OF MONTHLY VOLUMES FOR PERIOD OF RECORD					
						SEASONAL TREND			
	AVERAGE AMOUNT 1940-2016	ANNUAL TREND 1940-2016	ANNUAL TREND FOR 1960-2016	CUMULATIVE MONTHLY	36 MONTH ROLLING TOTAL	WINTER	SPRING	SUMMER	FALL
1	19.73	INCREASE	INCREASE	STEADY WITH SOME SMALL DEFLECTIONS	INCREASE	INCREASE	INCREASE	DECREASE	INCREASE
2	20.60	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	STEADY	DECREASE
3	24.10	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	INCREASE	DECREASE
4	23.20	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	INCREASE	DECREASE
5	25.90	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	INCREASE	DECREASE
6	27.31	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	INCREASE	INCREASE
7	24.59	INCREASE	INCREASE		INCREASE	INCREASE	DECREASE	INCREASE	INCREASE
8	28.15	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	INCREASE	STEADY
9	26.99	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	INCREASE	DECREASE
10	33.98	INCREASE	INCREASE		INCREASE	DECREASE	INCREASE	DECREASE	INCREASE
11	20.39	INCREASE	DECREASE		INCREASE	INCREASE	INCREASE	DECREASE	DECREASE
12	20.25	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	STEADY	INCREASE
13	22.97	INCREASE	STEADY		INCREASE	INCREASE	INCREASE	INCREASE	DECREASE
14	27.55	INCREASE	INCREASE		INCREASE	INCREASE	INCREASE	INCREASE	INCREASE

2.2.3 Analysis of Precipitation Information

Using the above information presented in Table 5 and Appendix B, the following general conclusions have been drawn with regard to precipitation trends at the study sites:

(1) The blue curve representing cumulative monthly precipitation (Figure 3 and Appendix B) indicates that no significant changes in precipitation volumes have occurred at any of the study sites; however, most study sites show small changes in the trend of the cumulative precipitation line when the 1950's drought ended and in a few other years when deflections in the cumulative precipitation information are noted.

(2) The green curve representing the annual precipitation and the red curve representing the 36-month rolling total precipitation both show a slight increasing trend (black dotted lines) over the period of record for each study site. However, the purple dashed line representing the annual trend since 1960 shows a decline for some of the sites.

(3) Seasonal patterns of precipitation (Table 5) show some variation throughout the period of record with several sites indicating some small declines in the long term trend for the fall season.

2.3 Naturalized Flow

The TCEQ has developed water availability models (WAM) for each of the 23 river and coastal basins in the State of Texas. These models are used by TCEQ to assess water availability when considering new water right applications or applications to amend existing water rights. One of the basic inputs to these models is a data set comprised of hydrologic time series of historical streamflows referred to as naturalized flows. These naturalized flows are derived using a spreadsheet analysis of historical data outside of the WAM for the purpose of defining the inflows that are used in the WAM.

2.3.1 Overview of Naturalized Flow Concept

For each river basin, the naturalized flows are derived by beginning with the observed (gaged) streamflows for the period record the observed flows are available. The monthly observed flows at a site then are adjusted to remove the effects of all historical water right and return flow activities so that these impacts are no longer represented in the flow time series. In other words, regardless of what specific diversion amounts or reservoir capacities the individual water rights are authorized, the actual amounts these activities used, in each month of the period of record, are either added to or subtracted from the observed flows. For diversions, reservoir evaporation losses, and amounts of water impounded in reservoirs, these quantities are added to the observed flows. For return flows or releases of water from one reservoir to another, these quantities are subtracted away from the observed flows. After this process is completed, the resulting flows are considered to be naturalized because they represent what the flows would have been at the subject site if all of these known and quantified activities had not occurred. This process is necessary for the WAM modeling process because it enables a future water right condition to be imposed on historical hydrologic conditions without the impact of historical water rights activities.

Two examples of how these naturalized flow data sets are used by the TCEQ to assess the effects of different water right conditions are:

> RUN3 – For each year of the period of record, all water rights of record divert their full authorized amounts and refill the full authorized capacity of any associated reservoirs without any return flow assumed to occur.
>
> RUN8 – For each year of the period of record, all water rights of record divert an annual quantity equal to the maximum amount they actually diverted during the most recent 10 years and refill the current capacity of any associated reservoirs (taking into account sedimentation effects) with return flows discharged at the minimum amount that was reported for the last five years.

In each of these scenarios, a demand condition is applied to the naturalized flow data set that represents a desired condition for analysis that is specified by the user, i.e., full utilization for the entire period of record as in RUN3 or current utilization for the entire period of record as in RUN8. Neither of these scenarios could be analyzed without having a naturalized flow data set because each scenario attempts to represent a single level of demand and reservoir configuration across the entire period of record, which cannot be reasonably accomplished if the historical actions of these same water use activities are not removed from the basic flow data set.

2.3.2 Use of Naturalized Flows at Project Study Sites

The latest naturalized flow dataset for the Colorado River basin was obtained from TCEQ. This dataset contains monthly time series of total naturalized flows for 45 gaged locations in the Colorado River Basin, 35 of which are in this project's study area. This dataset provides a continuous flow time series for each location for the period 1940-2013. Although the naturalized flows were created as input to the WAM models for the reasons stated earlier, they have been used extensively in this analysis to provide insight to historical anthropogenic impacts on observed flows. This was accomplished by comparing the observed and naturalized flows over the period of record, with the observed differences being the impacts of historical water use activities.

There is one notable exception to this. As noted earlier in the report, many of the study sites are missing observed streamflows for some part of the study period. For the missing period for these locations, the true flow naturalization process could not be accomplished because the observed flows are not known. Therefore, the TCEQ filled in the naturalized flows for these site's missing periods using flow relationships with nearby gages. In most cases, a relationship between naturalized flow for some other common period was derived and applied to fill in the unknown period. For these reasons, it was recognized that the naturalized flows for periods when the observed flows were missing at a study site should be given less credibility than the periods that had observed flows when evaluating trends over time. It should be noted that this issue has been reflected in all of the flow plots that will be introduced in the coming sections by depicting periods that were missing observed flows as blank during the missing periods.

With regard to TCEQ's naturalized flows, it should be noted that these flows approximate the amount of water that would have been present at a study site if the historical actions of the following activities had not occurred historically:

- diversions by all appropriative water rights
- storage and evaporation associated with major reservoirs
- discharge by large permitted dischargers.

Activities that are not adjusted for in the naturalized flow process are discussed in Chapter 3.

2.4 Comparisons of Streamflow, Precipitation, and Naturalized Flow

Using the information described in the previous sections, various information was combined together to facilitate an understanding of how the various quantities are related to each other over time at each study site. Two basic chart structures were created, both of which use the same information but are constructed differently to be able to evaluate different aspects of the runoff trends at each of the study sites.

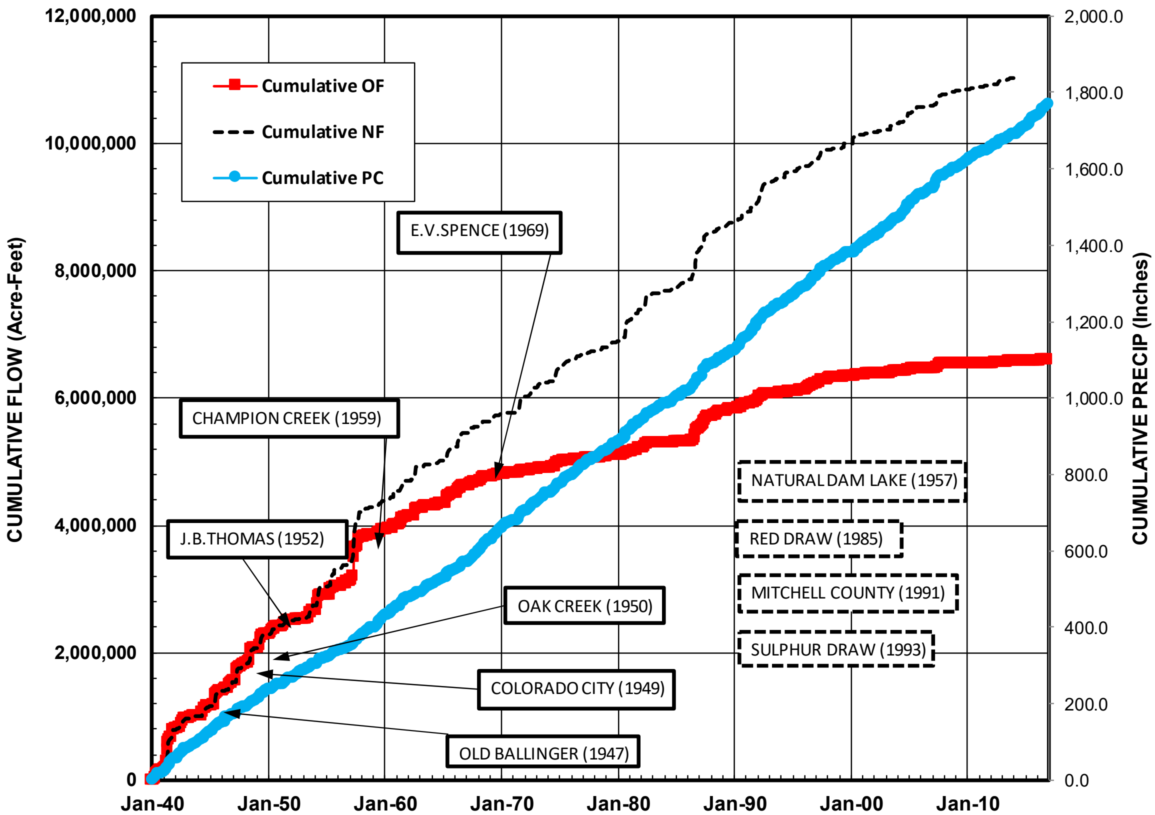
2.4.1 Incremental Flows

Most of the study sites (9 of the 14) are located on water courses that have streamflow gages located upstream. For these sites, there is an additional opportunity to gain understanding of the observed flow conditions by calculating the difference in flows between the upstream and downstream sites. By doing this, the incremental flow rising in the watershed between the gages can be isolated and evaluated, which can provide additional insight to the flow condition near the study site without being influenced by activities occurring upstream of the immediate upstream gage. However, it should be noted that this type of analysis often brings on another set of problems because of missing records at the upstream sites, which is required to determine the incremental flow. For instance, when computing incremental flow for a study site that has observed flows for the full period of record but only 20 years of observed flows at its upstream site, the only valid period of record that can be analyzed is the common period of the two gages, 20 years. Therefore, even though the full period of record is valid for analysis of the total flows at a study site, a significantly lesser period of record might be all that can be examined for the incremental watershed. For each of the 9 study sites that had upstream gaging stations, the incremental flows were calculated and examined even if the period was extremely limited. **Appendix C** details the study sites that have incremental watersheds along with the valid period of record associated with the incremental watershed. It should be noted that the incremental flow analysis for study site #3 resulted in meaningful information with regard to impacts on observed flow in the incremental watershed. Many of the other incremental flow analyses were too limited in period of record to provide meaningful information with regard to the trend of flow over the period of record.

2.4.2 Cumulative Mass Plots

A time based plot was generated to facilitate easy comparison of long term quantities of precipitation and flow at the study sites. An example of this type of plot is presented in Figure 4, again for study site #13.

Figure 4
Cumulative mass plot for study site #13
Colorado river near Ballinger



Monthly accumulated observed streamflow (Cumulative OF) and naturalized flow (Cumulative NF) are plotted on the left Y axis, cumulative monthly precipitation (Cumulative PC) is plotted on the right Y axis, with time in years on the X axis. Note that since the information on this plot is time based, it was also used to display the timeline of when the various major reservoirs were constructed in the watershed upstream of each study site. This information is presented in **Appendix D** for each of the study sites. This cumulative mass plot provides a means to observe the precipitation trace and both flow traces at the same time and to be able to examine precise periods along with knowledge of major reservoir construction dates. With regard to reservoir constructions dates, it should be noted that four of the major reservoirs upstream of this study site were not adjusted for in the naturalized flow process and thus are shown on the chart with dashed boxes with no arrows pointing to their construction date. These reservoirs will be further discussed in Chapter 5. Comparison of the difference between the observed and naturalized flow traces indicates the degree to which known water use activities have occurred upstream of the site. For most of the study sites, this comparison often falls into the following two classifications:

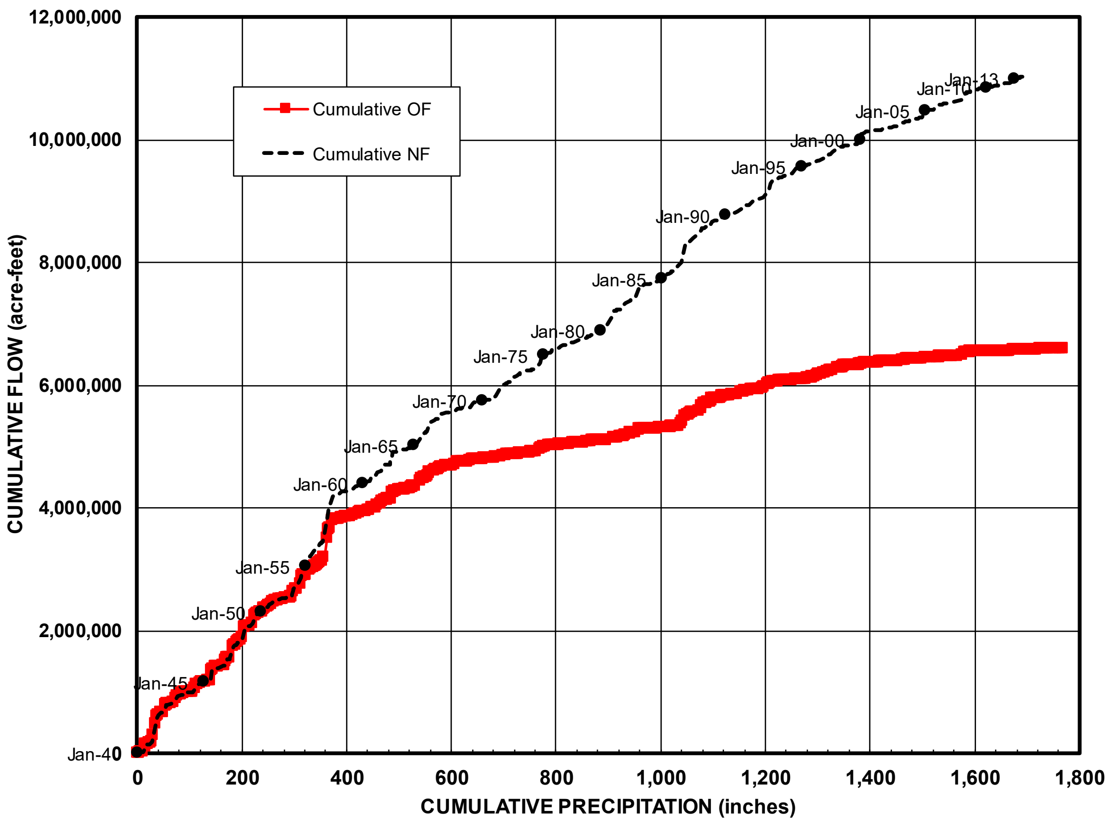
a. Little to no difference between the naturalized and observed traces, indicating there is very little historical utilization of water by known water rights in the watershed upstream of the site.

b. Large differences between the naturalized and observed traces, indicating there are large historical uses of water by known water rights upstream of the site, the extent of which is quantified over time by the difference between the two curves.

2.4.3 Double Mass Plots

Precipitation verses flow plots were also generated for each study site location. An example of this type of plot is presented in Figure 5, again for study site #13.

Figure 5
Double mass plot for study site #13
Colorado River near Ballinger



Monthly cumulative precipitation is on the X axis and both (1) cumulative naturalized flow (Cumulative NF) and (2) cumulative observed streamflow flow (Cumulative OF) on the Y axis. This information is presented in **Appendix E** for each of the study sites. The double mass plot shows the actual relationship of cumulative precipitation to both cumulative observed flow and cumulative naturalized flow without the constraint of a linear time scale as in the cumulative mass plots previously described. This means as time progresses and both flow and precipitation quantities are accumulated, they are plotted at the intersection of the two values, thus if both quantities go up and down together, there is no change in the resulting slope of the line. Similar to the cumulative mass plot, the difference between the observed and naturalized flow relationship with precipitation is an indication of the extent known water users impacted the flows observed flow at the study site.

2.4.4 General Conclusions of Observations

Based on review of the information summarized above for each of the study sites, it is apparent that, in most cases, the majority of the reductions in observed flows at many of the study sites are due to the water use/water storage activities of authorized water rights upstream, this being demonstrated by the difference between observed and naturalized flows in the plots presented. However, this is clearly not the case for some of the study sites, which show very little difference between observed and naturalized flows. In addition, even the study sites that show substantial impacts due to water use/water storage activities upstream, it is noted that the naturalized flow trace still indicates a declining trend for some portions of the period of record even after all adjustments for upstream water rights activities have been made, especially in the later years of the period of record. Table 6 provides a general summary of these observations for each of the study sites.

Table 6
Flow summary at study site locations

(1)	(2)	(3)	(4)	(5)	(6)
STUDY SITE #	SURFACE WATER INFORMATION				
	MONTHLY OBSERVED FLOW AND NATURALIZED FLOW				
	OBSERVED FLOW			NATURALIZED FLOW	
	DEGREE IMPACTED BY AUTHORIZED WATER RIGHTS	OVERALL TREND	RECENT TREND OF OBS. FLOW (2015-2016)	YEAR OF NOTED CHANGE IN TREND	OVERALL TREND
1	1	Declining	Large Inc.	1958, 1993	Declining
2	1	Declining	Small Inc.	1958, 1993	No Decline Until 1993
3	4	Declining	Small Inc.	1958, 1993	No Decline Until 1993
4	3	Declining	Small Inc.	1958, 2007	No Decline Until 2007
5	4	Declining	Small Inc.	1958, 1980	Declining
6	3	Declining	Small Inc.	1958, 1980, 2007	No Decline Until 2007
7	2	Declining	Large Inc.	1958, 1997, 2007	No Decline Until 1997
8	3	Declining	Large Inc.	1958, 1970, 1992, 2007	No Decline Until 2007 (except for 1970-1992)
9	2	No Decline Until 2007	Small Inc.	1958, 2007	No Decline Until 2007
10	1	No Decline Until 2007	Small Inc.	1958, 2007	No Decline Until 2007
11	4	Declining	Small Inc.	1968, 1993, 2005	Declining
12	4	Declining	Small Inc.	1968, 1993, 2005	Declining
13	4	Declining	No change	1958, 1993, 2005	Declining
14	4	Declining	Large Inc.	1993, 1997, 2007	No Decline Until 1993

Impact Degrees from lowest to highest are: (1) None, (2) Minimal, (3) Moderate, (4) Significant.

Other factors that may be impacting observed flows are explored in the next chapter, and the details of the various techniques used to better understand these activities are discussed.

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3.0 OTHER FACTORS THAT MAY BE IMPACTING FLOWS

This section describes other activities potentially impacting flows that have not been accounted for in of any of the flow information already presented. Several of these types of activities are discussed and information, however limited, is presented. It is important to consider whether any or all of these activities occurring upstream may be part of the answer, with the more important questions being to what extent these activities were in place and for what part of the study period. This is because the impacts of activities that cause flow depletions in the watersheds that are not adjusted for in the flow naturalization process are simply embedded in the naturalized flow values. Therefore, activities that did not occur until the middle or late part of the period of record can cause the monthly cumulative naturalized flows to show decreasing trends, like is noted for most of the study sites.

3.1 Small Reservoirs

As described in Chapter 1, the naturalized flows account for all depletions (evaporation, refilling storage, and diversion) of water by all major reservoirs in the basin and diversions of water made by other water rights, regardless of the size of the water right's authorized diversion amount. However, the process does not adjust for the amount of water impounded in smaller reservoirs with water rights (see Table 4, Chapter 1). In addition, water impounded in reservoirs that are exempt from the water rights permitting process are not considered in the naturalized flow process either. The next sections describe sources of information used to better understand the impact that small reservoirs could have on observed flows downstream. Additional information detailing an analysis of small reservoir's impacts on downstream water supply reservoirs is presented in section 4.1.

3.2 Exempt Water Rights

Section 11.142 of the Texas Water Code and Texas Administrative Code 297 provide several exemptions from having to obtain a water rights permit in order to use water from a State watercourse, which are based on the purpose the water is used for. This includes not only the right to consume water directly from the stream but also to construct reservoirs to impound water for these exempt uses. The following general limitations apply to reservoirs under these exemptions:

- Must have a normal capacity of less than 200 acre-feet.
- Must be built for purposes designated as exempt, such as livestock and domestic use.
- Cannot be constructed on a navigable stream.

Unlike appropriative water rights described in Chapter 1, exempt water rights do not have a priority date associated with their use of water (they are designated as being senior and superior to all other water rights), are not subject to priority calls by appropriative water rights during times of shortage, and are not required to file water use reports. For those exempt water rights that involve a reservoir for the stated exempt uses, there are no requirements for the owner to quantify the reservoir's location or size. Finally, these water rights are not evaluated based on any sort of review or consideration as to whether there is water available to support their use without impacting other water rights, either other exempt rights or appropriative water rights. Therefore, under the existing law and rules regarding exempt water rights, it is difficult to quantify the extent to which exempt water uses have impacted observed flow over time since little information is known about their use or location or the time when they were first used.

3.2.1 Techniques Use to Assess Impacts of Small Reservoirs

Two sets of information were explored to provide insight as to whether some part of the observed and naturalized flow declines noted in Chapter 2 could be attributed to impacts of small reservoirs, either by appropriative water rights or by reservoirs considered to be exempt from water rights permitting.

3.2.1.1 TCEQ Dam Safety Information

The TCEQ Dam Safety team is responsible for performing safety inspections of certain dams throughout the State of Texas, regardless of whether the dams are associated with an appropriative or an exempt water right[2]. As a result of maintaining this program, the team has created and continually updates a database and GIS coverage which details their safety inspection results for all dams they visit.

Among other information contained in this dataset are the location, name, owner, conservation and flood capacity, conservation and flood water surface area, and year built for each structure. A copy of this GIS information for the Colorado River Basin upstream of Mansfield dam was provided by the team and the information was merged into the study watershed GIS. Using the attributes in the GIS coverage, the number of dams in each of the WAM subwatersheds was determined, as well as the combined water surface area and combined storage capacity for all dams. It was noted, and confirmed by TCEQ staff, that no information is included in the Dam Safety database that indicates whether any of the dams are associated with appropriative water rights. Since this information was believed to be informative, the dam safety coverage was overlaid with the TCEQ water rights coverage (described in Chapter 1) and each dam location was reviewed. Locations that coincided with water rights in TCEQ's water right coverage were noted and this information was summarized for each of the WAM subwatersheds as well. Based on these results, of the 604 dams listed in the Dam Safety team's dataset for the study area, 174 dams are associated with at least one appropriative water right and the remaining 430 (71% of the total) appear to be dams that are exempt from the water rights permitting process. This information is presented in **Appendix F**.

Finally, so this information could be quantified to address the extent these small dams' flow depletions are not accounted for in the naturalized flow process, another total was computed without the major reservoirs included and with the year of dam completion broken out for each

[2] It should be noted that the water right information for small reservoirs that are based on appropriative water rights does not include a completion date; instead, a priority date. The priority date for dams authorized under the appropriative water rights system represents a legal date, such as the filing date of the associated water rights application, which can be substantially different from the date a dam was actually constructed.

decade for the period of record, 1940-2016. Note that this detailed breakout was done regardless of the legal classification of the dam (appropriative or exempt) because after the major reservoirs were removed, none of the remaining dams' ability to impound water were adjusted for in the flow naturalization process. This information is presented in Table 7.

Table 7
Summary of TCEQ dam safety information
Normal reservoir storage, by year completed, by WAM subwatershed

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
		TOTALS FOR DAMS NOT CONSIDERED IN NAT FLOW PROCESS (UNITS ARE ACRE-FEET)											
		TOTAL		NORMAL STORAGE AND YEAR COMPLETED									
STUDY SITE NUMBER	WS	TOTAL NUMBER OF DAMS	NORMAL STORAGE (ACRE-FEET)	Before 1940	1940-1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000	After 2000	Total After 1940	Total
	A3	14	1,607	83	326	103	822	273	0	0	0	1,524	1,607
	A2	1	76	76	0	0	0	0	0	0	0	0	76
11	A1	2	2,634	48	0	0	2,586	0	0	0	0	2,586	2,634
	B4	0	0	0	0	0	0	0	0	0	0	0	0
	B3	19	110,528	6,342	0	54,560	446	341	8,538	40,301	0	104,186	110,528
12	B2	9	742	225	0	457	30	30	0	0	0	517	742
	B1	0	0	0	0	0	0	0	0	0	0	0	0
1	C7	1	80	80	0	0	0	0	0	0	0	0	80
	C6	0	0	0	0	0	0	0	0	0	0	0	0
	C5	2	162	162	0	0	0	0	0	0	0	0	162
	C4	0	0	0	0	0	0	0	0	0	0	0	0
2	C3	3	550	550	0	0	0	0	0	0	0	0	550
	C2	9	1,429	1,027	0	360	42	0	0	0	0	402	1,429
3	C1	17	2,505	1,343	193	185	303	481	0	0	0	1,162	2,505
13	D4	39	5,970	172	0	1,469	3,845	468	16	0	0	5,798	5,970
7	D3	12	4,291	985	2,447	35	364	60	0	200	200	3,306	4,291
	D2	26	3,005	844	105	0	1,622	434	0	0	0	2,161	3,005
	D1	63	6,401	0	0	123	3,691	1,504	1,020	63	0	6,401	6,401
4	E4	2	420	280	0	0	0	0	140	0	0	140	420
	E3	1	53	53	0	0	0	0	0	0	0	0	53
5	E2	44	5,303	35	101	4,237	930	0	0	0	0	5,268	5,303
6	E1	23	2,571	418	40	624	292	876	197	124	0	2,153	2,571
	F3	119	15,086	4,317	481	0	8,925	1,293	70	0	0	10,769	15,086
8	F2	51	5,072	125	133	0	2,398	2,416	0	0	0	4,947	5,072
14	F1	63	9,244	1,174	276	2,714	1,469	3,161	450	0	0	8,070	9,244
	G5	1	62	0	0	0	62	0	0	0	0	62	62
	G4	3	809	197	0	0	300	312	0	0	0	612	809
	G3	2	252	252	0	0	0	0	0	0	0	0	252
	G2	0	0	0	0	0	0	0	0	0	0	0	0
9	G1	5	894	383	0	317	44	90	0	60	0	511	894
	H2	1	100	0	0	0	100	0	0	0	0	100	100
10	H1	9	987	124	0	0	732	131	0	0	0	863	987
	I4	5	1,574	0	0	830	0	189	0	0	555	1,574	1,574
	I3	2	242	0	187	0	55	0	0	0	0	242	242
	I2	35	2,797	144	58	14	1,143	466	670	302	0	2,653	2,797
Study Area Tot		583	185,446	19,439	4,347	66,028	30,201	12,525	11,101	41,050	755	166,007	185,446

Based on review of Table 7, it is observed that several of the WAM subwatersheds have a significant volume of storage constructed in the middle to late part of the period of record. For these watersheds, the fact that most of the dams were built in the mid and later period of record means that these dams have impacted flows, to some extent, that were observed downstream in the later part of the period of record but did not impact flows in the early part of the period, before they were constructed. It is recognized that this type of occurrence, in some cases, might help explain lower observed and naturalized flow trends in the later period of record. Accordingly, an approach to test these observations for study site #5 was created and is detailed in Chapter 5.

Table 8 presents the information from column 13 of Table 7 (reservoirs built after 1940, not adjusted for in the naturalized flow process), but summarizes the total number of dams and the associated storage volume within the watershed of each of the 14 study sites. With regard to Table 8, the following should also be also noted:

(1) The total number of dams for the 3 most downstream study sites (#12, #13, #14) reflect two sets of totals. This is because the watershed upstream of Beal's Creek near Westbrook (WAM subwatershed B3) was excluded from the totals in columns 4, 5, and 6. More information for the reasons for the different treatment of the Beal's Creek watershed can be found at the end of Chapter 5.

(2) The information reported includes all dams upstream of each study site. Therefore, study sites that are downstream of other study sites reflect some of the same dams in both totals. Column 6 in Table 2 (presented in Chapter 1) lists which study sites have other study sites in their upstream watershed.

Table 8
Summary of TCEQ dam safety information
Reservoirs upstream of study sites, completed after 1940 and not included in naturalized flow process

	(1)	(2)	(3)	(4)	(5)	(6)
	ALL WATERSHEDS UPSTREAM			(1) NOT INCLUDING BEAL'S CREEK (B3)		
STUDY SITE NUMBER	NUMBER OF RESERVOIRS	COMBINED SURFACE AREA (acres)	COMBINED NORMAL STORAGE (acre-feet)	NUMBER OF RESERVOIRS	COMBINED SURFACE AREA (acres)	COMBINED NORMAL STORAGE (acre-feet)
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	13	348	1,564	13	348	1,564
4	1	0	140	1	0	140
5	43	1,378	5,268	43	1,378	5,268
6	65	1,804	7,561	65	1,804	7,561
7	10	179	3,306	10	179	3,306
8	161	1,518	15,716	161	1,518	15,716
9	7	140	1,185	7	140	1,185
10	8	120	963	8	120	963
11	14	321	4,110	14	321	4,110
12	33	7,105	108,813	19	371	4,627
13	70	8,372	114,611	56	1,638	10,425
14	464	14,851	159,390	450	8,117	55,204

With regard to the TCEQ Dam Safety information, the following should be noted:

- The database only contains dams that were inspected by the TCEQ Dam Safety Team.
- The selection of which dams get inspected is driven by factors other than the number of dams in a watershed. For instance, dams that are considered to be high hazard, had a complaint filed for various reasons, or simply were noticed while the team was in the field are the main reasons for inclusion in the database. Therefore, the database's total number of dams by watershed cannot be taken as a representation of the total number of dams that actually exist in that watershed.

3.2.1.2 NHD Water Body Information

The second technique used the National Hydrography Dataset (NHD) GIS coverage provided by the USGS that depicts "small water bodies" in the study area. This coverage was created in about 2003 by the USGS using land use and aerial photo information and identifies the location and exposed surface water area for all water bodies, regardless of size. This information was merged with the study's watershed coverage to provide the ability to quantify the number of water bodies and the combined water surface area for each WAM subwatershed in the study area. The attributes of this GIS coverage were then modified by removing the coverage's representation of each of the major reservoirs that were accounted for in the naturalized flow process (discussed in Chapter 2) so that the number of water bodies and their associated water surface area could be determined to quantify the extent to which water bodies exist in the watersheds that are not accounted for in the naturalized flow process. This was accomplished, but there are several problems with this information that make it difficult to compare to the Dam Safety information described earlier. With regard to this information, the following should be noted:

- The water surface area given in the coverage only relates to the amount of water that was apparent in the feature when the source information was collected.
- The number of features does not necessarily constitute a count of actual manmade reservoirs. Several of the features on larger river reaches in the study area appear to identify natural pools that might not be appropriately considered to be manmade reservoirs. In addition, large parts of the most western area of the upper Colorado River Basin have numerous natural features, such as playa lakes, that are counted by the process as water bodies.
- In some cases, many of the larger waterbodies were represented as several separate waterbodies adjoining each other, thus the count of individual water bodies may be overstated.
- Water bodies that had an area of less than 0.25 acres were counted as water bodies but a water surface area was not reported in the coverage attributes.
- The coverage does not contain the following information:
    - The maximum water surface area of the water bodies depicted.
    - The water storage capacity for any water body feature.
    - The year in which the water body came into existence.

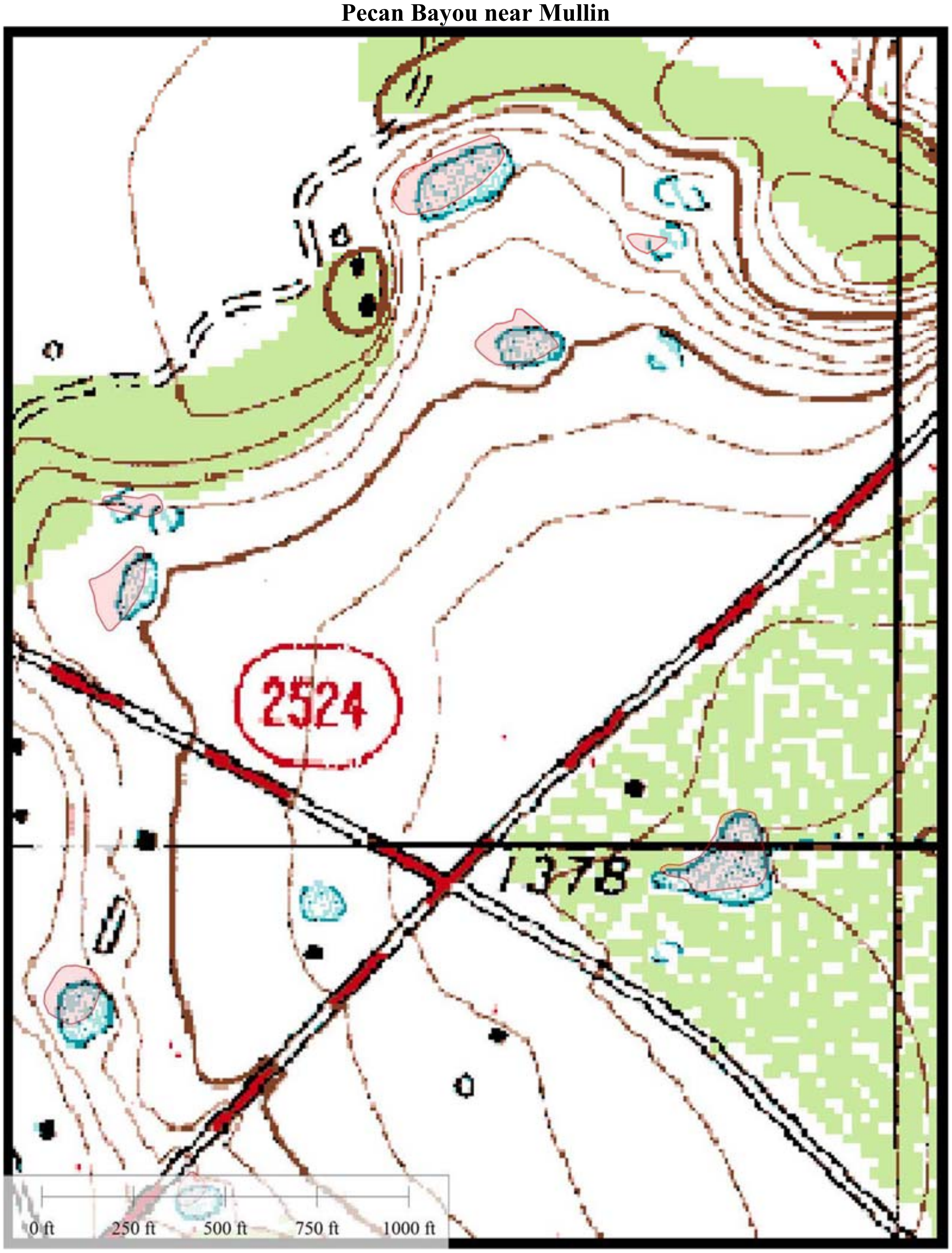
Although this information lacks many of the parameters needed to be able to quantity these water bodies' ability to impact observed flows over time, this information is somewhat useful for understanding which of the study areas have more or less small water bodies in their watershed upstream that could impact flows. **Appendix G** summarizes this information for each WAM subwatershed in the study area, after the major reservoirs discussed in Chapter 1 have been removed. Note that the total number of water bodies was also broken into several water surface area size categories to better understand how the total number of water bodies exist within the specified size categories. Using the summary information presented in Appendix G, the total number of water bodies in columns 4, 5, and 6 divided by the total in column 2 indicates that almost all the water bodies listed have an area of 5 acres or less (97% of the total number of water bodies for entire Upper Basin and 98.5% for the portion of the basin between Colorado River at Stacy, Pecan Bayou near Brownwood, and Mansfield Dam). Table 9 provides a summary of the water body information totaled for each study site watershed, similar to what was presented in Table 8 for the Dam Safety information. However, it should be noted that the information in Table 9 includes all water bodies in the water body coverage, regardless of when they were built, because the water body coverage does not contain information about when the water body came into existence.

Table 9
NHD small water body summary, by study site
Water bodies not included in naturalized flow process

	(1)	(2)	(3)	(4)	(5)	(6)
STUDY SITE NUMBER	ALL WATERSHEDS UPSTREAM			NOT INCLUDING BEALS CREEK (B3)		
	NUMBER OF WATER BODIES	COMBINED SURFACE AREA	COMBINED NORMAL STORAGE	NUMBER OF WATER BODIES	COMBINED SURFACE AREA	COMBINED NORMAL STORAGE
1	849	833	NA	849	833	NA
2	273	157	NA	273	157	NA
3	6,280	9,531	NA	6,280	9,531	NA
4	748	828	NA	748	828	NA
5	1,384	1,605	NA	1,384	1,605	NA
6	6,039	4,596	NA	6,039	4,596	NA
7	2,852	1,631	NA	2,852	1,631	NA
8	16,092	11,028	NA	16,092	11,028	NA
9	7,718	3,732	NA	7,718	3,732	NA
10	3,258	1,843	NA	3,258	1,843	NA
11	4,924	6,971	NA	4,924	6,971	NA
12	14,606	39,357	NA	7,049	8,576	NA
13	19,441	42,335	NA	11,884	11,554	NA
14	67,554	79,284	NA	59,997	48,503	NA

As an example of what the NHD small water body coverage looks like, Figure 6 shows the coverage overlaying the Brownwood USGS topographic map (photo revised in 1987) for a select area in the watershed of study site #8 (Pecan Bayou at Mullin) with the water bodies the coverage identified shown in the light pink crosshatch. It should be noted that the coverage identifies most of the reservoirs clearly identifiable on the topographic map, although not all. It should also be noted that none of the small reservoirs in this view were listed in the Dam Safety database or had appropriative water rights associated with them.

Figure 6
Example of water body coverage
for part of WAM subwatershed F2 (study site #8)
Pecan Bayou near Mullin



3.3 Noxious Brush

The proliferation of noxious brush[3] in many watersheds in Texas has been a concern with respect to flow depletions for many years, and such conditions are present in many of the watersheds upstream of several of the study sites. Numerous reports and feasibility studies were reviewed to gain an understanding of the brush densities in the study site watersheds along with the published results of monitoring efforts for several ongoing and completed projects in the study area. The TCEQ's naturalized flows that were heavily relied upon to provide insight to the runoff issues of the study area do not reflect any adjustments for increases in brush acreages in the basin. Instead, similar to the exempt reservoir discussion in the previous section, the extent brush densities have increased over time and reduced the flow reaching the study site locations is simply imbedded in the observed and naturalized flows. Therefore, to the extent acreages of brush have increased in the watersheds and depleted more water over time, these unaccounted for depletions could be responsible for some portion of the declining trend of flow noted in Chapter 2.

3.3.1. Legislative History of Funding for Brush Control Activities

The 69th Texas Legislature enacted the Brush Control Program Act in 1985 and designated the Texas State Soil and Water Conservation Board (TSSWCB) the task of administering the program. The statute was codified in Chapter 203 of the Texas Agriculture Code, and in 1986 the TSSWCB adopted a Brush Control Plan. In 1999, the Texas Legislature appropriated funds to implement the Brush Control Program for the next 12 fiscal years (2000-2011) and the TSSWCB developed an approach to prioritize proposed projects based on the magnitude of the impacted areas and the likelihood of each project's success. In 2011, the Texas Legislature passed HB 1808, which made numerous changes to the law and ended the Texas Brush Control Program, replacing it with a new program called the State's Water Supply Enhancement Plan and again the TSSWCB was made administrator of the program.

Since 1998, The TSSWCB has been accepting feasibility studies of conducting brush control for water supply enhancement in many watersheds across Texas. These feasibility studies estimate the potential water quantity increases that could be expected if various assumed percentages of the targeted brush varieties were removed from the proposed watershed. Typically, a small scale rainfall-runoff model such as the Surface Water Assessment Tool (SWAT) is used to model the surface water flows of a watershed under the existing brush density condition, then re-run with some or all of the targeted brush varieties removed with the difference between the simulated surface water flows in each scenario compared. To date, 20 feasibility studies have been conducted and published for targeted areas across the state, half of which are located in the Colorado River basin upstream of Lake Travis. In addition, the TSSWCB publishes a list identifying feasibility studies that are proposed in the near future, with 4 of the 17 proposals also being located in the Colorado River basin upstream of Lake Travis.

Once a feasibly study has been approved and a brush control project is funded, the TSSWCB oversees the implementation of the project. The tracts of land that are cleared of the targeted

[3] Noxious Brush is loosely defined by the TSSWCB as brush varieties that are considered to be detrimental to water conservation and agriculture production activities.

species are inventoried to determine the location and extent of acreage that has been cleared, and water savings information from the approved feasibility study are usually applied to the numbers of acres that are actually cleared to estimate water savings. In some cases, monitoring of actual surface and groundwater conditions after brush control has been accomplished are also used to estimate the benefit of brush clearing, as example of which is discussed in Section 3.3.2.1.

3.3.2 TSSWCB Brush Control Projects in the Study Area

There are four projects that have been either completed or are in progress in the study area. The feasibility documents were reviewed along with any monitoring results that were available. In addition, telephone conversations were conducted with managers of each of the projects and information was provided on the problems and benefits of the projects.

3.3.2.1 North Concho Brush Control Project

By far, the project with the largest area identified with brush problems is the North Concho watershed, which is represented by study site #1. This project is said to be the impetus for state and federal brush control projects in Texas. Based on information from feasibility studies submitted in the mid and late 1990's and additional information made available from the TSSWCB, ash juniper and honey mesquite are the 2 varieties targeted for removal with approximately 430,000 acres (671.9 square miles) to be removed. The amount of additional flow that could be realized by completing the project for the land areas proposed is stated as 38,000 acre-feet per year, or about 30,000 acre feet per year more than what was determined to be the condition before the brush control program.

The information in the Concho River Watershed Protection plan states that removal of the targeted brush varieties began in 2001 with a total of 340,000 acres (530 square miles) being treated by mechanical means by about 2011. The project was completed over a multiyear period and was followed by a 10-year hydrologic response monitoring program which ended in 2012. Review of the monitoring results reported in 2006 show some small gains in streamflow and small rises in groundwater levels, and it is reported that the alluvial aquifers have risen, resulting in the North Concho River carrying more water downstream. It should be noted that information in the feasibility studies for this project assumed that the aquifers in the area would be replenished to pre-1962 levels before most of the increases in surface water flows could be expected to occur, a condition that was not expected to occur for many years after the brush control project was completed. It is also noted that much of the monitoring period in 2000-2010 experienced dryer than average precipitation amounts, which probably diminished the expected streamflow increases. Finally, as part of the monitoring efforts, an evapotranspiration study was conducted in the North Concho watershed, the results of which are detailed in Chapter 4.

The area of the North Concho watershed upstream of study site #1 is 1,202 square miles, thus if the entire area actually treated was upstream of the study site, this would represent approximately 44% of the drainage area of study site #1; however, the exact location of the cleared acreages with respect to the North Concho at Carlsbad gage is not clear in the information reviewed. With regard to the flow trends analyzed for this study, no discernable increase in flow was observed until 2015, which does show an increase; however, it is not clear if the noted increase is attributable to completed brush control activities or above average precipitation amounts occurring over the last two years.

3.3.2.2 E.V. Spence Watershed

The Colorado River Municipal Water District implemented a brush control project in the watershed upstream of E.V. Spence Reservoir in 2006. The project targeted salt cedar (Tamarisk) which had infested the riparian area near the Colorado River between J.B. Thomas and E.V. Spence Reservoirs. Over a period of 3 years, approximately 11,390 acres of salt cedar were treated by chemical means. No documentation of increases of flows, or reduction of river losses, due to the treatment was available.

3.3.2.3 Pedernales Watershed

The TSSWCB in Johnson City is managing a brush control project for the Pedernales River watershed upstream of Lake Travis. The project is still ongoing and work began in 2001. To date approximately 73,000 acres of juniper have been removed using mechanical techniques. No analysis has been made of the increases in flows from this effort.

3.3.2.4 Pecan Bayou Watershed

The TSSWCB in San Angelo is about to start work on a brush control project in the Pecan Bayou watershed upstream of Lake Brownwood. At this time, some amount for funding has been made available but no work has been initiated.

3.3.3 Review of Other Brush Control Information

There are several other smaller brush control activities that have been accomplished by individual land owners throughout the study area, which are not addressed individually in this report. Many of these efforts have reported that the removal of ash juniper and mesquite have resulted in the restoration of seeps and resulted in streamflow for longer periods of time after rainfall events. However, based on review of numerous documents containing experts' opinions regarding the extent brush removal can be expected to produce significant quantities of water flowing into the streams downstream, it is clear that there is disagreement with regard to the actual water savings that can be expected. Many opponents point out that whatever brush that is successfully removed will be replaced naturally with some other plant, resulting in little net gain in streamflows. Proponents of brush control assert information that shows there are almost no other plants that can use the amount of water many of the targeted brush varieties utilize. No information was uncovered in this study that could be used to quantify the extent ash juniper and mesquite have impacted streamflows over time. Several documents pertaining to recent studies of brush control issues are discussed in Chapter 4.

3.3.4 GIS Based Information for Brush Varieties

Information from the TSSWCB contains numerous feasibility studies that were the basis for selection of the various watersheds that are either being proposed for brush control action or are have projects in progress, as detailed above. However, no information could be found from the TSSWCB that consistently quantifies the number of acres of the various brush species for any portion of this project's study area, either for the current period or periods before the brush problems were thought to have begun. Several other information sources were explored to determine if some GIS based process currently exists that could be used to quantify brush densities in the study area, and these are summarized below.

The Texas Parks and Wildlife has a program called Texas Ecosystem Analytical Mapper (TEAM) which provides the ability to review general types of vegetation for the entire state of Texas. This system was reviewed and attempts were made to quantify ash juniper and mesquite densities for study site #1. Although there are several classifications of vegetation that include the varieties of interest, they are combined with other varieties of trees/brush and thus could not be isolated for the varieties needed. In addition, the coverages are pixel based with no existing process readily available without analysis techniques outside of this project's scope and budget to calculate acreages for the various categories. Finally, the vegetation information for this program was developed using recent (2005-2007) GIS land use data and aerial photography; thus, even if this information could be refined where it could be used specifically to assess the varieties of interest, it would not enable any kind of quantification of brush densities associated with the early years of this project's study period, information that would be needed to understand how changes in brush densities over time may or may not have impacted observed streamflows.

The Texas Forest Service has similar information related to the density of brush throughout the state as it relates to fire fuel risk. Similar to the TPWD TEAM program, this information also was not found to be useable to compute acreages of the targeted brush varieties by watershed, and there appears to be no information related to brush densities for any period other than recent.

3.4 Land Use Changes

Basic land use information was examined from various sources, including review of GIS based land use coverages from various sources, published documents, census records, land ownership information, and farm and livestock information from the United States Department of Agriculture. The largest land use related changes in the basin have already been addressed in topics covered earlier in this chapter (noxious brush and small reservoirs). The following sections summarize the basic information related to population growth and livestock and farming practices.

3.4.1 Census Information

Census information from the Texas Association of Counties was obtained showing the population of each predominant county in the study area, by each decade of the study's period of record. The population was noted for each decade of the 1940-2010 period, and the percent the population each county changed from 1940 to 2010 were calculated to provide insight to the general growth rates in the counties that cover the major portions of the watershed in the study area. As expected, counties located in and near large populations centers had higher growth rates than rural counties, with several rural counties showing less population in 2010 than in 1940. The information is presented in Table 10. Increases in population in the more urban counties generally translate to increased development and more impervious cover of the land surface, factors that are known to increase runoff and, hence, streamflows. However, considering the relatively small portion of the study watershed that is urbanized, it is unlikely that this change in land use could have significantly impacted streamflows, with the exception of localized areas immediately downstream of urban centers.

Table 10
Population by decade for study area counties

	COUNTY	1940	1950	1960	1970	1980	1990	2000	2010	% INCREASE FROM 1940 POPULATION
1	BLANCO	4,264	3,780	3,657	3,567	4,681	5,972	8,418	10,497	146.2%
2	BORDEN	1,396	1,106	1,076	888	859	799	729	641	-54.1%
3	BROWN	25,924	28,607	24,728	25,877	33,057	34,371	37,674	38,106	47.0%
4	BURNET	10,771	10,356	9,265	11,420	17,803	22,677	34,147	42,750	296.9%
5	COKE	4,590	4,045	3,589	3,087	3,196	3,424	3,864	3,320	-27.7%
6	COLEMAN	20,571	15,503	12,458	10,288	10,439	9,710	9,235	8,895	-56.8%
7	CONCHO	6,192	5,078	3,672	2,937	2,915	3,044	3,966	4,087	-34.0%
8	GILLESPIE	10,670	10,520	10,048	10,553	13,532	17,204	20,814	24,837	132.8%
9	GLASSCOCK	1,193	1,089	1,118	1,155	1,304	1,447	1,406	1,226	2.8%
10	HOWARD	20,990	26,722	40,139	37,796	33,142	32,343	33,627	35,012	66.8%
11	LAMPASAS	9,167	9,929	9,418	9,323	12,005	13,521	17,762	19,677	114.7%
12	LLANO	5,996	5,377	5,240	6,979	10,144	11,631	17,044	19,301	221.9%
13	MASON	5,378	4,945	3,780	3,356	3,683	3,423	3,738	4,012	-25.4%
14	MCCULLOCH	13,208	11,701	8,815	8,571	8,735	8,778	8,205	8,283	-37.3%
15	MENARD	4,521	4,175	2,964	2,646	2,346	2,252	2,360	2,242	-50.4%
16	MILLS	7,951	5,999	4,467	4,212	4,477	4,531	5,151	4,936	-37.9%
17	MITCHELL	12,477	14,357	11,255	9,073	9,088	8,016	9,698	9,403	-24.6%
18	NOLAN	17,309	19,808	18,963	16,220	17,359	16,594	15,802	15,216	-12.1%
19	RUNNELS	18,903	16,771	15,016	12,108	11,872	11,294	11,495	10,501	-44.4%
20	SAN SABA	11,012	8,666	6,381	5,540	6,204	5,401	6,186	6,131	-44.3%
21	SCHLEICHER	3,083	2,852	2,791	2,277	2,820	2,990	2,935	3,461	12.3%
22	SCURRY	11,545	22,779	20,369	15,760	18,192	18,634	16,361	16,921	46.6%
23	STERLING	1,404	1,282	1,177	1,056	1,206	1,438	1,393	1,143	-18.6%
24	TAYLOR	44,147	63,370	101,078	97,853	110,932	119,655	126,555	131,506	197.9%
25	TOM GREEN	39,302	58,929	64,630	71,047	84,784	98,458	104,010	110,224	180.5%
26	TRAVIS	111,053	160,980	212,136	295,516	419,573	576,407	812,280	1,024,266	822.3%

3.4.2 Land Ownership Trends

The Texas A&M Natural Resources Institute has a program called Texas Land Trends that monitors population growth along with changes in land use, land ownership size, and land values of privately owned Texas farms, ranches, and forests. Information from this database generally suggests that growth rates in counties near large growing urban centers has brought about the fragmentation of large rural properties into smaller parcels due to increasing land market values and the rising demand for individuals to own and live on small rural tracts. To better understand the extent of change occurring in Upper Colorado Basin, the information for the counties at and upstream of the study sites (listed in Table 10 in the previous section) was obtained and analyzed. It should be noted that this information is limited only to properties that are classified as agriculture or wildlife exempt, thus only represents rural properties in the study area. A summary of the information is presented in Table 11A and Table 11B.

Table 11A
Number of farm/ranch operations in study area counties

	Year	1-99 ac.	100-499 ac.	500-999 ac.	1000-1999 ac.	2000+ ac.
(1)	Year	1-99 ac.	100-499 ac.	500-999 ac.	1000-1999 ac.	2000+ ac.
(2)	1997	6,078	7,149	2,684	1,709	1,479
(3)	2002	6,316	7,001	2,378	1,594	1,437
(4)	2007	7,724	7,501	2,311	1,562	1,496
(5)	2012	7,576	7,175	2,144	1,600	1,452
(6)	Change: 1997-2012	1,498	26	-540	-109	-27
(7)	% Change 1997 - 2012	24.6%	0.4%	-20.1%	-6.4%	-1.8%

Table 11B
Total number of acres by land parcel size in study area counties

	Year	1-99 ac.	100-499 ac.	500-999 ac.	1000-1999 ac.	2000+ ac.
(1)	Year	1-99 ac.	100-499 ac.	500-999 ac.	1000-1999 ac.	2000+ ac.
(2)	1997	224,032	1,746,499	1,881,343	2,366,852	8,746,672
(3)	2002	243,621	1,677,235	1,662,225	2,207,652	8,391,706
(4)	2007	278,244	1,769,074	1,623,838	2,184,407	8,636,582
(5)	2012	275,215	1,695,930	1,484,211	2,225,662	8,745,212
(6)	Change: 1997-2012	51,183	-50,569	-397,132	-141,190	-1,460
(7)	% Change 1997 - 2012	22.8%	-2.9%	-21.1%	-6.0%	0.0%

As can be seen in Table 11A, from 1997-2012 there has been a large increase in the number of small farm/ranch operations with a corresponding decline in the number of large-scale operations (Row 7). Likewise, Table 11B shows the total number of acres owned in the smaller tract classification has increased for the same period with a corresponding decline in the acreage owned in most of the larger parcel classifications (Row 7). Based on discussion with Texas Land Trends staff, this information suggests that there may be land use changes occurring in the watershed upstream of the study sites associated with the additional smaller tracts of land and additional owners, one of which may be the opportunity for construction of more small ponds and reservoirs to serve the growing number of small rural properties, with most of these types of small impoundments likely exempt from water rights permitting. As has already been discussed, the effects of small ponds and reservoirs may be significant with respect to capturing runoff and reducing streamflows.

3.4.3 Livestock Information

The USDA provided a limited amount of information related to livestock populations for most of the counties in the study area. This information was summarized by calculating the percent change for the period of record available, which was different for the various common livestock varieties, and was only available for the later portion of the study period. This information is presented in Table 12. Based on this information, it is noted that there has been a substantial decline in almost all of the animal counts in almost all of the counties reviewed for the period information was available.

Table 12
Change in common livestock populations in study area counties

COUNTY	CATTLE	GOATS	HOGS	SHEEP
	PERCENT CHANGE FROM 1975-2016	PERCENT CHANGE FROM 1993-2015	PERCENT CHANGE FROM 1974-2012	PERCENT CHANGE FROM 1975-2015
BLANCO	-52%	-55%	-96%	-64%
BORDEN	-80%	NA	NA	NA
BROWN	-36%	29%	-96%	-61%
BURNET	-50%	114%	-97%	-71%
COKE	-67%	17%	-83%	-90%
COLEMAN	-44%	61%	-99%	-92%
CONCHO	-51%	-53%	NA	-89%
GILLESPIE	-29%	-22%	-99%	-63%
GLASSCOCK	-69%	-57%	-96%	-60%
HOWARD	-28%	NA	NA	NA
LAMPASAS	-57%	-48%	-94%	-78%
MCCULLOCH	-60%	-78%	-98%	-85%
MASON	-40%	-85%	-100%	-88%
MENARD	-50%	-74%	NA	-83%
MILLS	-44%	-62%	-100%	-38%
MITCHELL	-61%	NA	-50%	-73%
REAGAN	-57%	NA	NA	-92%
RUNNELS	-53%	43%	-97%	-74%
SAN SABA	-53%	-47%	-100%	-90%
SCHLEICHER	-63%	-13%	NA	-61%
STERLING	-42%	-48%	NA	-80%
TOM GREEN	-57%	-4%	-88%	-76%
TRAVIS	-65%	133%	-98%	20%

3.4.4 Farming Practices

The USDA also a provided limited amount of information related to the number of cultivated acres for the counties in the major part of the study area. This information contained the number of acres cultivated for each crop cultivated for the period 1968-2016. The information was reviewed and summarized by simply computing the total cultivated acreage by county for all crops combined and is presented as **Appendix H** (yellow shaded cells represent the year in which the maximum cultivated acreage occurred in each county). This information shows that cultivated acreage has generally declined for the counties in the central part of the study area and increased for many of the counties in the west and north areas of the study area.

3.5 Groundwater

Groundwater pumpage from aquifers is not explicitly considered in the flow naturalization process described in Chapter 2. Therefore, after coming to the conclusion in Chapter 2 that other activities besides upstream surface water rights might be impacting observed streamflow trends, available ground water information was reviewed and assembled to better understand trends in groundwater pumping and use.

The TWDB has numerous sources of information regarding observed groundwater conditions in the study area. This information was obtained in GIS and Excel formats and merged into the study's GIS watershed coverage so that the various types of information could be quantified and compared among study sites and the associated WAM subwatersheds.

The information includes:

- Water well locations.
- Groundwater use by county.
- Elevations of groundwater over time.

3.5.1 Well Locations

The following 2 groundwater well inventories were obtained from TWDB:

- Submitted Drillers Report Database (SDRDB). This database contains well location information taken from drillers' logs for all wells drilled for the period 1996-2015. This information was merged with the study's watershed coverage to count the number of wells drilled recently drilled, by WAM subwatershed, for the study area. A summary of this information is presented in **Appendix I** which shows that over 60,000 water wells were drilled in the study area since 1996, with approximately 50% of these wells drilled in WAM subwatershed B3 (Beal's Creek near Westbrook), most of which were drilled for energy production purposes.
- Groundwater Database (GWDB). This dataset contains well location information for all wells in the state, including the wells already represented in the SDRDB. This dataset was used in GIS to understand locations and general densities of wells in the various watersheds and also to locate specific monitoring wells of interest.

3.5.2 Groundwater Use

Historical groundwater pumpage by county was downloaded from the TWDB's website and processed into an Excel spreadsheet. This information contains groundwater use information for all counties in the state for the period 1980 through 2014 by county, by aquifer. A spreadsheet process was used to summarize this information for the counties most related to the study sites and a detailed summary of this information is presented in **Appendix J**. The maximum annual groundwater use for the period of record is highlighted in yellow and is also specified in the right column of the appendix (pages J-5 through J-8). It should be noted that for the 129 county/aquifer reported use records presented in the appendix, the maximum annual use for the 1980-2014 period most frequently occurred in 2011, followed closely by 2010.

3.5.3 Groundwater Monitor Well Information

Historical groundwater elevation information was obtained from the TWDB for each of the counties of interest. Each of these county databases have many thousands of records recording daily groundwater elevation observations for several hundred wells. This information was processed so that the specific details for each well could be summarized by county, aquifer, number of observations, and time range of observations. Wells that had at least 5 observations covering a reasonable time range were plotted and analyzed. Aquifers that showed declines in groundwater elevations were examined closer by reviewing the reported use described above for the county, and this information was used to help rationalize possible reasons for the otherwise unexplained reductions in observed and naturalized flows for several of the study sites. A summary of groundwater elevation by county and by aquifer, which includes general observations with regard to groundwater trends, was combined with the groundwater use information described in Section 3.5.2 and is presented in **Appendix K**. Table 13 summarizes this information for the counties upstream of the study sites that showed some amount of decline in groundwater elevation for the study period of record. Time series charts of this information are presented in **Appendix L** and analysis of this information is presented in Chapter 5. Study sites not included in Table 13 (study site numbers 7, 8, 12, and 13) were noted as generally having either stable or increasing groundwater elevations over the period of record.

Table 13
Summary of aquifers near study sites with groundwater declines

	AQUIFER NAME	COUNTY	ASSOCIATED STUDY SITE
(1)	Dockum	BORDEN	11
(2)	EDWARDS-TRINITY-PLATEAU	GLASSCOCK	1
	EDWARDS-TRINITY-PLATEAU	MENARD	4, 5
	EDWARDS-TRINITY-PLATEAU	STERLING	1
(3)	ELLENBURGER-SAN SABA	GILLESPIE	9,10
	ELLENBURGER-SAN SABA	LLANO	9
	ELLENBURGER-SAN SABA	MASON	9,6
	ELLENBURGER-SAN SABA	MCCULLOCH	5,6
	ELLENBURGER-SAN SABA	MENARD	4,5
(4)	HICKORY	CONCHO	3,5
	HICKORY	GILLESPIE	9,10
	HICKORY	MCCULLOCH	5,6
	HICKORY	MENARD	4, 5
	HICKORY	SAN SABA	6,14
(5)	LIPAN	TOM GREEN	1,2,3
	LIPAN	CONCHO	3
(6)	TRINITY	GILLESPIE	9,10

3.5.4 Springflow

There are 10 springs in the entire study area for which published flow data were found in USGS's records. These springs are listed in Table 14 along with their approximate period of record, general vicinity, and associated aquifer[4].

Table 14
Springs in study area with published information

	APPROX OBSERVED RECORD	GAGE#	GAGE NAME	COUNTY	GENERAL LOCATION	ASSOCIATED AQUIFER
(1)	1945-2016	08129500	Dove Creek Spring nr Knickerbocker	Irion	Upstream of San Angelo	Edwards Trinity Plateau
(2)	1994-2019	08149395	Tanner Spring nr Telegraph	Edwards	Upstream of City of Junction	Edwards Trinity Plateau
(3)	1943-2016	08143900	Springs at Ft. McKavett	Menard	Upstream of City of Menard	Edwards Trinity Plateau
(4)	1959-2016	08149500	Seven Hundred Springs nr Telegraph	Edwards	Upstream of City of Junction	Edwards Trinity Plateau
(5)	1953-2016	08146500	San Saba Spring at San Saba	San Saba	Near City of San Saba	Marble Falls
(6)	Minimal	08103500	Hanna Springs at Lampasas	Lampasas	Near City of Lampasas	Marble Falls
(7)	Minimal	08127200	Anson Springs nr Christoval	Tom Green	Upstream of City of Christoval	Edwards Trinity Plateau
(8)	Minimal	08129000	Spring Ck Springs nr Mertzon	Irion	Upstream of City of Mertzon	Edwards Trinity Plateau
(9)	Minimal	08152710	Felps Springs nr Burnet	Burnet	2 1/2 Miles South of City of Burnet	Trinity
(10)	Minimal	08152715	Delaware Springs nr Burnet	Burnet	2 Miles SSW of City of Burnet	Trinity

A time series plot of discharges from springs 1-5 as separate graphs and then a single plot showing discharges from the last 5 springs are presented in **<u>Appendix M</u>**. Review of these plots shows most of the springs that have recent observed discharge data (#1,#2,#3,#4,#5) indicate a clear decline after about 2010. It is also noted that the springs that have observed flow in both the 1950's and after 2010 indicate that the most recent observed springflows are very compatible with the quantities observed in the 1950's, with much higher discharge rates for much of the period in between.

[4] Texas Water Development Board, Report 189, Major and Historical Springs of Texas, March 1975.

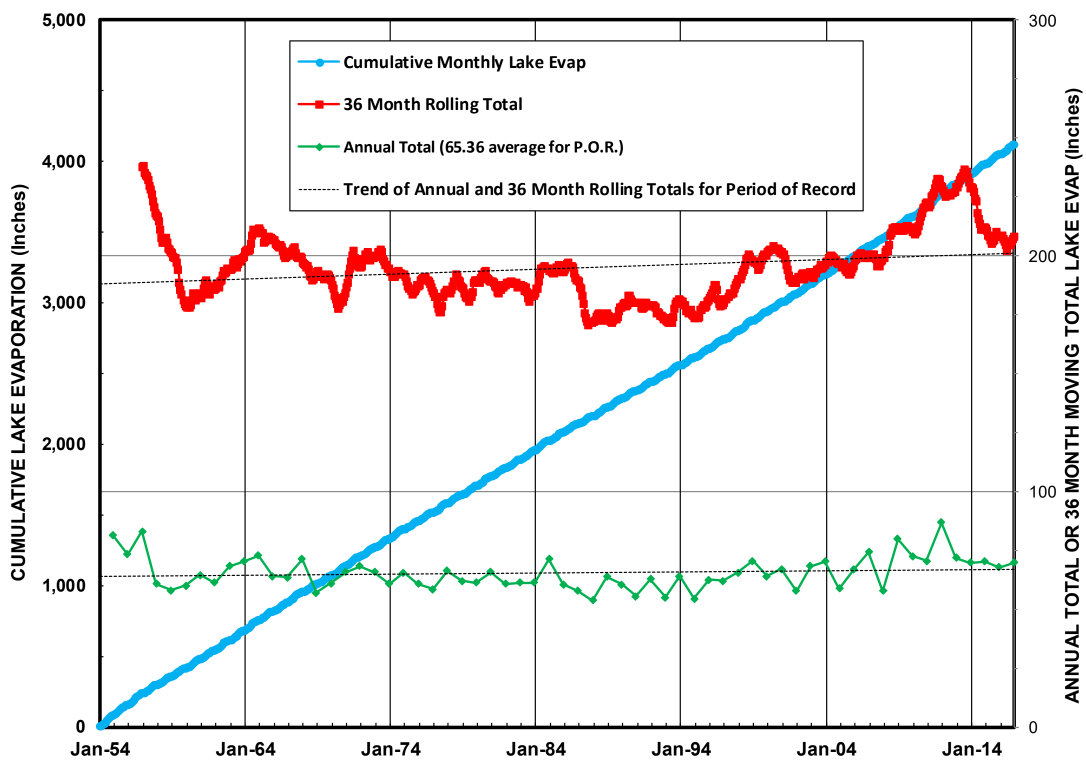
3.6 Evaporation Rates

Evaporation rate information for the study area was assembled and analyzed for the longest period of record for which information was available. This information was summarized using similar techniques used to analyze long term trends of precipitation and flow discussed in earlier chapters.

3.6.1 TWDB Evaporation Information

The TWDB publishes monthly evaporation rates by 1 degree quadrangles, for the period of record 1954-2016. The center of Quadrangle 608 is near O.H. Ivie Reservoir and was selected as a reasonable representation of the general study area. The TWDB evaporation rates are referred to as "lake evaporation" rates, which means they represent the gross evaporation loss in inches from a lake surface. This information is produced by adjustment of numerous daily observed evaporation readings from pan evaporation stations located across the state. After the raw data from the pan evaporation stations are totaled into monthly values, a Theissen polygon network is used to weight the information from different pan locations to the center of each 1 degree quadrangle. This information is presented in Figure 7 for Quadrangle 608. Based on review of this graph, historical lake evaporation for the period 1954-2016 indicates a slightly increasing trend (black dashed line) for the period 1954-2016 for both the total annual lake evaporation quantity as well as the 36 month rolling total quantity. Note that Chapter 4 summarizes another study which made similar conclusions.

Figure 7
TWDB lake evaporation information for quad 608



3.7 Temperature

Temperature information from NCEI records were downloaded and a process similar to what was described in the precipitation discussion in Chapter 2 and was utilized to assess trends. Many of the precipitation observation stations used and described in Chapter 2 also have some amount of observed temperature data but most only for a limited period. However, records at major airports and military bases were found to have complete or nearly complete records for the period of record 1940-2016. This information was reviewed and found to include very few average daily values but nearly continuous records for maximum and minimum daily observed values. To estimate average daily values for the periods that only had maximum and minimum daily values, the daily maximum and minimum values were averaged. These results were compared to the actual observed average values for the periods when common records were available and found to be almost the same.

This information for the Austin Camp Mabry and San Angelo Mathis Field stations were processed, and the following graphics were created for both sites, using the daily average temperature as defined above:

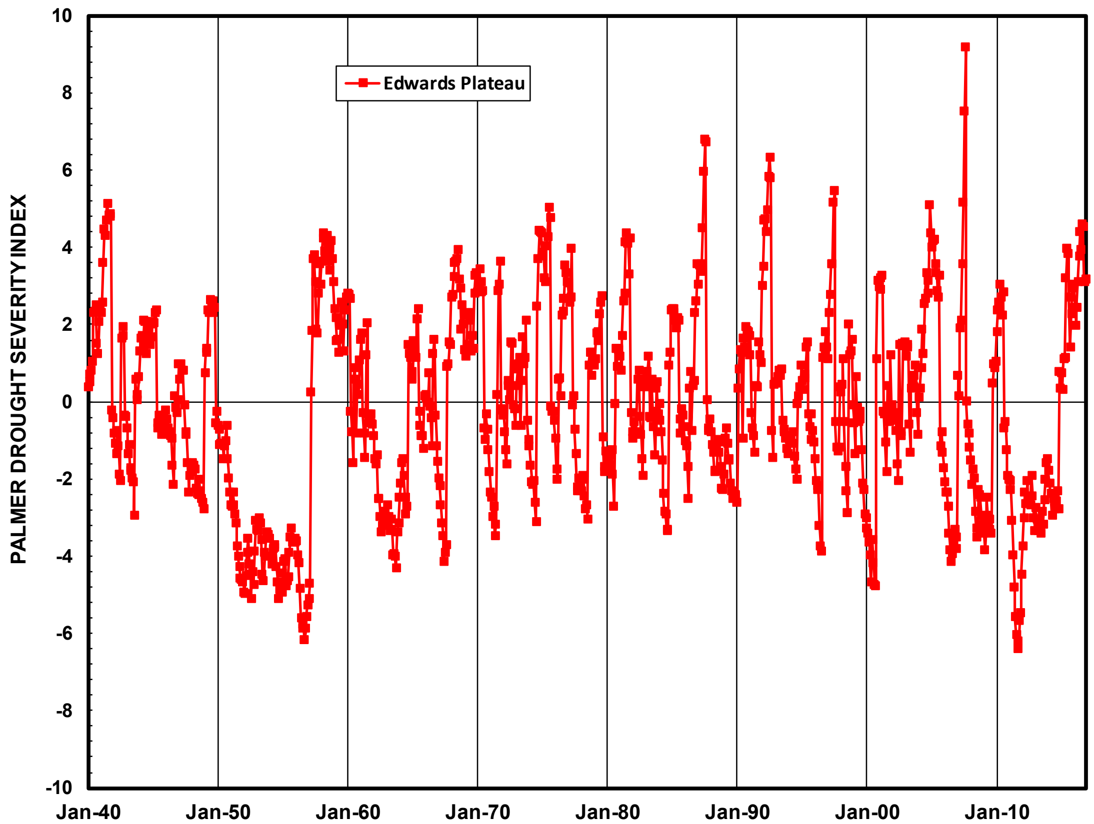
(1) Plot Showing 36 Month Running Average and Monthly Average of the Daily Average Temperature.
(2) Plot Showing the Number of Days per Year the Daily Average Temperature Exceeded Various Specified Temperatures.
(3) Decadal Frequency Matrix Showing Daily Average Temperature Exceedance Percentages.

The results for Austin Camp Mabry are presented in **Appendix N** and the results for San Angelo Mathis Airfield are presented in **Appendix O**. Based on review of these results, it is clear that the average temperature across the study area has increased over the period of record. This single factor alone suggests that evapotranspiration, evaporation, and many other factors that affect soil moisture conditions and water consumption may have correspondingly increased in the later period of record. Additional information is presented in Section 4.7 that documents recent analysis of this concept.

3.8 Historical Drought Condition

The Palmer Drought Severity Index (PDSI) was obtained from the National Oceanic Atmospheric Administration (NOAA) for the three climatic divisions that cover the study area for the full period of record, 1940-2016. This information uses temperature and precipitation data to estimate relative dryness and has a standardized index ranging from -10 (dry) to +10 (wet) to represent moisture conditions. The majority of the study area falls in the Edwards Plateau climatic division, with the most northern and western areas being in the High Plains and Low Rolling Plains climatic divisions, respectively. Figures 8 shows these results for the Edwards Plateau climatic division for the period of record 1940-2016.

Figure 8
Palmer Drought Severity Index (PDSI)
for Edwards Plateau division



Plots for the other two climatic divisions demonstrated similar trends. It is noted that the most recent drought period (~2011) was more extreme than any year of the period of record including the drought of the 1950's but that the 1950's drought lasted longer. Also, it is noted that the most recent period (from about 1990-2014) indicates large extremes, with both large positive and negative index values.

3.9 Soil Moisture

It is widely known that the antecedent condition of a watershed has a significant influence on the amount of precipitation that actually results in observed flow in watercourses downstream, and one of the largest influencers of antecedent condition is soil moisture. Other than the PDSI[5] information presented in the previous section that was used to infer overall wet and dry conditions over the project period of record, no other information was found that could be used to quantify historical soil moisture conditions in the study site watersheds. However, there are

[5] The Standardized Precipitation Index and Standardized Precipitation Evaporation Index are other indices with comparable records to PDSI that have been used in other studies to provide insights to historical soil moisture conditions.

several new efforts being implemented that plan to be able to track and monitor this type of information in the future and these activities are described in the following sections.

3.9.1 Gravity Recovery and Climate Experiment (GRACE)

The Gravity Recovery and Climate Experiment (GRACE) project was begun in March 2002 with the launch of a National Aeronautics and Space Administration (NASA) satellite. This satellite measures anomalies in the earth's gravitational forces and uses this information to estimate changes in water distribution across the planet. A specific example of one application of the use of this information to estimate soil moisture conditions in Central Texas is summarized in Section 4.2 of this report.

3.9.2 Soil Moisture Active Passive Observatory (SMAP)

This project was initiated with the launch of a NASA satellite January 30, 2015. In anticipation of this project, the Texas State Soil Observation Network (TxSON), which is operated by the University of Texas at Austin's Bureau of Economic Geology, began in late 2014. This project began by installing numerous soil moisture monitors in the Pedernales River watershed (within the watershed of study site #10) which were tied into the Lower Colorado River Authority's existing Hydromet System. Since that time, numerous additional soil moisture/weather stations have been installed in other areas of the study area including near Brady, Texas (study site #5). The main purpose of these soil moisture measurement stations is to (1) be able to validate and calibrate soil moisture information from the SMAP satellite, and (2) be able to use real time soil moisture information for estimating runoff that is likely to occur given real time knowledge of precipitation events in the area.

3.9.3 National Data Land Assimilation System (LDAS)

A methodology is being researched by NOAA, NASA, National Center for Atmospheric Research, Princeton University, and the University of Washington which uses existing Surface Vegetation Atmosphere Transfer Schemes (SVATS) at 1/4th-degree resolution globally to evaluate soil moisture conditions. These LDAS systems have been run retrospectively starting in January 1979 and continue in near real-time and use precipitation observations, satellite data, radar precipitation measurements, and output from numerical prediction models. Eventually, observations of LDAS storages (such soil moisture, temperature, snow) and fluxes (including evaporation, sensible heat flux, runoff) will be used to further validate and constrain the LDAS predictions using data assimilation techniques.

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4.0 LITERATURE REVIEWED

Numerous documents were reviewed to gain insight regarding changes in observed flows in the vicinity of the Upper Colorado River basin. Each of these documents is listed in the reference section of this report, with what are believed to be the more relevant documents summarized in this chapter.

4.1 Effects of Small Surface Water Impoundments on Water Supply Reservoirs

The impacts small ponds and impoundments can have on downstream water supply activities was investigated by R.J. Brandes Company and URS (R.J.Brandes and others, 2011) for two watersheds in Texas, one of which was in the Lake Coleman watershed (upstream of study site #8 - Pecan Bayou at Mullin). The other was for Cedar Creek Reservoir, a large water supply reservoir located several hundred miles east of the study area in the Trinity River basin. This study used the SWAT model to simulate runoff from the watershed of Lake Coleman in response to daily rainfall, with various simulations made with different assumed numbers of stock ponds located throughout the watershed at densities of 0, 4, and 8 ponds per square mile. Results of the analysis indicated that the assumed number of small ponds in the watershed had a substantial impact on the firm yield of Lake Coleman, reducing its yield on the order of 25-34 percent from yield estimates with no small ponds upstream. Similar results from this analysis of Cedar Creek Reservoir also indicated a reduction in yield, but the impacts were not nearly as significant, on the order of 13-17 percent.

The first conclusion of the study was that the number of small ponds located in a watershed significantly impacts the flows at downstream locations. In addition, because the impacts were so much larger for the Lake Coleman watershed, it was also concluded that the amount of precipitation a watershed typically receives has a large influence on how much small ponds can impact downstream flows, with the watershed that receives less annual average precipitation being impacted more by the addition of ponds upstream. Although the precise watershed of Lake Coleman was not selected as a specific study site for the analysis herein, study site #8 includes the Lake Coleman watershed. This study site location received an average annual precipitation amount of 28.15 inches for the period 1940-2016, with almost all of the other study sites receiving less than this amount.

4.2 Hydrologic Studies of the Highland Lakes Watershed Part 1; Why are the Recent Flows so Low?

Intera Geoscientist and Engineering Solutions (Intera, 2015) performed an analysis in which many of the same issues identified in this report were also analyzed. This earlier study focused on an area of the Colorado River watershed that rises below the dams that form O.H. Ivie and Brownwood Reservoirs. It is noted that the USGS NHD small water body GIS coverage also was used in this study to estimate the number of water bodies in the watershed between O.H. Ivie and Brownwood Reservoirs and Lake Travis' Mansfield Dam, which was reported to be 44,258 impoundments with a combined water surface area of about 26,400 acres, generally consistent with what is reported in Chapter 3. In addition, the study used GRACE satellite data, which monitors minor differences in the earths gravitational readings, to estimate relative soil moisture conditions for the period 2002 through 2015 and concluded that since late 2011, soil moisture conditions have been well below average and that a substantial soil moisture deficit existed in the Colorado River Basin in their study area. The report concludes that rainfall events have been father apart, and that this coupled with the soil moisture deficit and the number of small impoundments have resulted in recent observed flows being lower than what would otherwise have occurred.

4.3 Contrasting Watershed-Scale Trends in Runoff and Sediment Yield Complicate Rangeland Water Resource Planning

Texas A&M AgriLife (Berg and others, 2016) recently published a study that focused on a portion of the Lampasas River watershed, which is in the Brazos River basin but adjacent to the Colorado River basin near study site #14. The analysis examined a period of record from 1924-2010 and concluded that neither precipitation rates nor observed streamflows showed any directional trend up or down over the period. In addition, the authors examined baseflow conditions and concluded that baseflows have actually increased a small amount over the period 1924-1980. The study notes that there have been numerous landscape changes over the period of record, including the placement of 8 flood control reservoirs on tributaries, generally changing land use from crop land in the early years to rangeland in the latter, large fluctuations in the extent of woody plant cover due to brush management and re-growth over the period, and a dramatic increase in the density of farm ponds. Even with these changes, the study concludes that the observed streamflow trend over the long term has not changed, leading to the conclusion that “this raises doubts over efforts to increase runoff by directing land cover changes”.

4.4 Effect of Brush Control on Evapotranspiration in the North Concho Watershed Using the Eddy Covariance Technique

The Journal of Soil and Water Conservation (Saft and others, 2014) published a document that details a study in the North Concho watershed in which evapotranspiration from two 200-acre tracts of land that were dominated with honey mesquite were monitored after one of the tracts had been mechanically cleared. The study recorded evapotranspiration information from both tracts for a period of about 4 years, from 2005-2008. The study’s conclusion found that an average of about 0.7 of an inch less evapotranspiration occurred on the treated tract than was measured on the untreated tract for the 4 year study period. There was no information presented with regard to changes in surface water flows or groundwater levels in or around the study area.

4.5 River System Hydrology in Texas

The Texas Water Resource Institute (Texas Water Resource Institute, 2014) published a document detailing the analysis of 35 streamflow gaging stations in Texas in which long term precipitation, observed flows, and naturalized flows were analyzed. The Colorado River near San Saba (study site #14) was one of the sites they analyzed. Similar to the study conducted herein, naturalized flow was used to assess declines in observed streamflows over time that was due to known water resource activity and the study made the following conclusions:

(1) Based on review of precipitation information for the entire State of Texas, no long term trends in monthly observed precipitation could be seen. Trends, or long term changes, if they exist, are hidden in the extreme variability inherent in precipitation.
(2) Monthly evaporation rate information indicate that evaporation rates appear to be increasing since 1960 in the majority of the 1 degree quadrangles analyzed, which leads to the study's further conclusion that the statewide mean evaporation rate is increasing for the same period.
(3) Numerous small reservoirs, that are not included in the data presented in their study, may also be affecting flows into the river systems. The following groups of unaccounted for reservoirs are listed in their report as follows:
   (a) The Natural Resource Conservation Service, which has constructed almost 2,000 flood retarding structures in Texas.
   (b) Cities, which have constructed numerous stormwater detention facilities throughout the state.
   (c) Land owners, which have constructed many ponds with storage capacities less than 200 acre-feet or less that are exempt from the water right requirements.

The study also reports that comparisons of observed verses naturalized flow for Colorado River at San Saba site indicate that the mean annual naturalized flow is 142% of mean annual observed flow for the period 1940-2012. It should be noted that the same calculation made from the results of the study herein show a result of 138% for the period of record 1940-2016.

4.6 Long Term Trends in Streamflow from Semiarid Rangelands: Uncovering Drivers of Change

A study (Wilcox and others, 2008) was conducted for the North (study site #1), Middle, and South Concho River watersheds (study site #2) that attempted to answer the question "has observed streamflow in dry-lands been altered as a result of vegetation changes on the rangelands, and if it has, to what extent?". The study asserts that there was significant over-grazing for many decades prior to the 1950's drought in this area and that the drought conditions in the 1950's brought about significant reductions in the livestock carrying capacity for the period between 1950 and 1992, reducing stocking to about 40% of what they were during the pre-1950 period.

In addition, using limited aerial photo information, the study noted that there were extensive areas of woody plants in 1954 but most were in riparian zones and that by 1979, woody plants had expanded into almost all areas. Baseflow/stormflow separation analysis was done for each of the three watersheds and the study found that the stormflow component in all three watersheds has decreased significantly since the 1960's, but the baseflow component only showed a slight decrease in the North Concho with no change to a slight increase in the other two watersheds. To further expand the finding that storm runoff was the component that has changed, the study analyzed two 24-year periods in the North Concho watershed that had comparable precipitation

(1926-1949 and 1974-1997) and compared runoff relationships for 63 of the largest runoff-producing events from these periods along with 12 of the largest runoff events from another period after much of the large scale brush control had been implemented (2001-2005). Their findings were that comparisons between the 1926-1949 and 1974-1997 periods did in fact show significant reductions in the rainfall-runoff relationships for the later period (1974-1997) leading the author to conclude that the landscape in the early period was much more prone to producing runoff and flooding. However, comparing rainfall/runoff relationships from the 1974-1997 period with the period selected after brush control had been implemented (2001-2005) did not show much difference. In fact, the author concludes runoff appears to be "even less sensitive" to precipitation in the 2001-2005 period after large scale brush control had been implemented.

The general conclusions of the study assert the following two points:

(1) The reason for the relatively high runoff amounts in the pre-1950's period compared to lower rates for the post 1960 period is 'hydrologic recovery" in the later period. The higher runoff rates seen in the pre-1950's period were a product of overgrazed and generally degraded rangelands and the lower runoff rates seen after the 1960's were a product of an improving rangeland, the recovery of which was facilitated by the increase in woody plants that provide cover and protection to the soils when there was little else in the way of vegetation.
(2) In semiarid rangelands, where baseflow is a small component of the total streamflow, large scale scrub/brush clearing will not lead to significant increases in streamflow because proper management will likely lead to vigorous vegetation to be maintained, which means that infiltration rates will remain high and water will be maintained in the soil and eventually used by plants.

4.7 Global Assessment of Flood and Storm Extremes with Increased Temperature

This recent report (Wasko and others, 2017) describes an analysis of how recent increases in temperatures correspond to changes in precipitation and observed streamflow. Using global datasets of observed temperature, precipitation, and streamflow information, the author identified precipitation events and streamflow events along with the observed temperature during each event. Using scaling techniques with these results, the author concluded that while increases in temperature typically result in increases in precipitation, this increase in precipitation does not result in a corresponding increase in observed streamflow, at least not for normal or moderately high precipitation events. The result of this research suggests that other abstractions, such as soil moisture conditions, change in response to the increase in temperature and that these changes result in less of the precipitation producing streamflow, even though precipitation increased.

5.0 ANALYSIS OF STUDY SITES

5.1 Overview of Detailed Analysis

The following sections provide observations of the information assembled in this study that summarize the rainfall/runoff relationships for each of the 14 study sites in the upper Colorado River Basin. The map of the study area (Figures 1A and 1B) introduced in Chapter 1 should be referred to for detailed location information for each site. In addition, several of the study sites' detailed descriptions rely on judgements made based on:

(1) Cumulative mass plots presented in Appendix D.
(2) Double mass plots presented in Appendix E.
(3) Groundwater reported use and groundwater elevation summary information presented in Appendix K.
(4) Groundwater elevation for select counties and aquifers presented in Appendix L.

Table 15 summarizes the basic information for precipitation, observed flow, and naturalized flow in tabular form, for each of the study sites. The information is structured as follows:

(1) Columns 3-11 present the decadal annual average amounts for precipitation, observed flow, and naturalized flow.
(2) Column 12 presents the annual average amounts for precipitation, observed flow, and naturalized flow for the period 1940-2013. Note that this is the total period for which naturalized flows are available.
(3) Column 13 presents the annual average amounts for precipitation, observed flow, and naturalized flow for the study's full period of record, 1940-2016, with the precipitation quantity shaded in pink.
(4) Column 14 presents the annual average amounts for precipitation, observed flow, and naturalized flow for 1956.
(5) Column 15 presents the annual average amounts for precipitation, observed flow, and naturalized flow for 2011.
(6) Column 16 presents the percent that the values in Column 15 for 2011 are of the values in Column 14 for 1956.
(7) It should be noted that the average values for the observed flow could not be calculated for some of the periods described above because of missing periods of record. These periods are noted as "missing" and shaded blue.

In many cases, this table shows that observed flows and even naturalized flows are substantially lower in the most recent decades compared to what was seen in the earlier decades, even though the precipitation was about the same, or even greater, in the more recent decades. In addition, columns 14, 15, and 16 compare results specifically for 1956 and 2011. Although these two years are not necessarily comparable for all study sites, they were typically the lowest years of precipitation for most of the study sites. As is indicated for several of the study sites, even when the precipitation for 2011 was greater than 1956, the observed and naturalized flows are often significantly less than what was noted for 1956.

Table 15
Average annual quantities
of precipitation, observed, and naturalized flow
by decade and most severe drought years

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1)	Study Site #	Description of Quantity	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2013	2010-2016	1940-2013	1940-2016	1956	2011	% Col 15 is of Col 14
(2)		# of Years	10	10	10	10	10	10	10	4	6	74	77	1	1	
(3)	SITE#1-N CONCHO RV NR CARLSBAD															
(4)	1	PRECIP	21.48	15.89	20.03	19.37	20.17	20.45	21.21	17.18	18.91	19.66	19.72	8.18	5.64	68.9%
(5)	1	OBS. FLOW	26,417	27,452	6,963	8,603	11,178	4,598	4,916	2,096	5,255	12,293	12,182	13,236	465	3.5%
(6)	1	NAT. FLOW	26,638	27,611	7,240	8,638	11,177	4,610	4,929	2,077	NA	12,388	NA	13,429	465	3.5%
(7)	SITE#2-S CONCHO RV AT CHRISTOVAL															
(8)	2	PRECIP	23.19	17.14	19.47	19.07	23.12	20.27	21.30	17.78	21.47	20.36	20.60	8.13	9.21	113.3%
(9)	2	OBS. FLOW	14,885	20,886	10,753	27,734	16,408	MISSING		4,829	8,568	MISSING		3,497	3,044	87.1%
(10)	2	NAT. FLOW	14,857	20,911	10,939	27,949	16,530	16,505	13,497	4,937	NA	16,644	NA	3,505	3,112	88.8%
(11)	SITE#3 CONCHO RV AT PAINT ROCK															
(12)	3	PRECIP	23.41	19.74	23.73	23.20	26.22	26.29	25.31	21.82	25.24	23.87	24.10	15.41	12.10	78.5%
(13)	3	OBS. FLOW	126,025	118,873	25,518	54,787	49,472	53,800	19,038	22,526	30,563	61,692	60,897	27,164	10,996	40.5%
(14)	3	NAT. FLOW	141,123	158,309	68,181	150,791	118,892	104,387	56,125	35,300	NA	109,720	NA	70,953	18,578	26.2%
(15)	SITE#4-SAN SABA RV AT MENARD															
(16)	4	PRECIP	25.74	17.21	21.71	27.04	22.55	23.94	24.54	19.87	22.73	23.06	23.20	14.80	11.02	74.5%
(17)	4	OBS. FLOW	37,149	43,377	16,683	53,586	24,827	MISSING	30,831	14,442	16,248	MISSING		50,817	9,479	18.7%
(18)	4	NAT. FLOW	39,886	49,389	23,064	58,782	28,236	54,632	32,714	16,781	NA	39,651	NA	57,075	13,372	23.4%
(19)	SITE#5-BRADY CR AT BRADY															
(20)	5	PRECIP	25.46	20.93	24.92	27.59	25.64	28.11	28.32	24.65	26.41	25.79	25.90	12.66	12.06	95.3%
(21)	5	OBS. FLOW	10,244	29,883	3,367	12,880	MISSING			840	1,816	MISSING		10,129	10	0.1%
(22)	5	NAT. FLOW	10,244	29,884	6,415	18,453	5,273	9,120	5,560	3,457	NA	11,666	NA	10,130	100	1.0%
(23)	5	ADJ NF(1)	7,881	27,666	6,381	18,453	5,273	9,120	5,560	3,457	NA	11,043	NA	8,078	100	1.2%
(24)	SITE#6-SAN SABA RV AT SAN SABA															
(25)	6	PRECIP	27.69	24.58	27.04	26.17	24.77	31.54	29.13	25.38	27.70	27.17	27.31	14.15	20.11	142.1%
(26)	6	OBS. FLOW	142,970	147,486	120,185	180,950	80,361	MISSING	109,970	60,399	71,597	MISSING		118,312	28,204	23.8%
(27)	6	NAT. FLOW	147,023	155,125	133,593	197,863	93,195	154,658	120,467	68,639	NA	139,105	NA	127,736	37,882	29.7%
(28)	SITE#7-ELM CR AT BALLINGER															
(29)	7	PRECIP	23.97	22.56	25.13	25.17	25.45	23.74	25.09	20.33	26.01	24.22	24.59	19.55	13.46	68.8%
(30)	7	OBS. FLOW	28,854	37,025	25,927	34,122	26,333	38,593	18,570	6,057	13,936	28,628	28,465	51,337	1,122	2.2%
(31)	7	NAT. FLOW	28,948	37,580	27,301	35,043	28,879	41,141	19,870	7,143	NA	29,949	NA	52,125	1,704	3.3%
(32)	SITE#8-PECAN BAYOU AT MULLIN															
(33)	8	PRECIP	28.92	24.24	27.48	25.81	25.64	34.95	29.77	26.79	28.51	28.04	28.15	19.43	25.08	129.1%
(34)	8	OBS. FLOW	MISSING			69,809	72,178	218,448	123,927	17,218	111,220	MISSING			16,195	NA
(35)	8	NAT. FLOW	229,679	239,463	208,610	117,092	122,980	254,974	161,183	47,575	NA	182,839	NA	212,279	22,901	10.8%
(36)	SITE#9 - LLANO RV AT LLANO															
(37)	9	PRECIP	27.92	25.31	26.80	26.78	26.38	27.60	28.79	25.01	26.12	26.97	26.99	12.30	15.25	124.0%
(38)	9	OBS. FLOW	219,631	228,040	252,922	335,064	269,492	331,574	282,776	125,385	145,929	266,169	262,552	27,540	48,359	175.6%
(39)	9	NAT. FLOW	221,435	231,122	258,822	343,190	277,455	338,079	286,770	129,467	NA	271,440	NA	31,246	52,658	168.5%
(40)	SITE#10-PEDERNALES NR JOHNSON CITY															
(41)	10	PRECIP	35.09	33.69	33.48	33.51	30.90	36.35	34.37	32.06	34.65	33.81	33.98	15.62	17.42	111.5%
(42)	10	OBS. FLOW	117,135	128,751	92,248	182,832	142,599	186,006	176,840	57,776	73,447	141,827	139,977	5,079	10,263	202.1%
(43)	10	NAT. FLOW	116,515	128,314	94,584	183,970	142,197	185,436	176,093	56,855	NA	141,872	NA	4,974	9,787	196.8%
(44)	SITE#11-COLORADO RV AT COLORADO CITY															
(45)	11	PRECIP	21.00	17.47	21.08	20.91	20.10	21.09	22.07	14.22	18.96	20.19	20.39	11.90	8.19	68.8%
(46)	11	OBS. FLOW	MISSING	35,814	25,378	18,717	32,099	14,097	11,312	2,633	10,380	MISSING		8,020	671	8.4%
(47)	11	NAT. FLOW	80,040	67,822	52,111	38,255	60,780	33,707	28,927	7,375	NA	49,269	NA	16,528	3,006	18.2%
(48)	SITE#12-COLORADO RV ABV SILVER															
(49)	12	PRECIP	21.13	15.44	20.17	19.79	20.68	21.15	24.37	17.14	18.89	20.21	20.25	8.18	5.64	68.9%
(50)	12	OBS. FLOW	MISSING			45,488	83,664	37,258	28,936	17,950	25,878	MISSING				NA
(51)	12	NAT. FLOW	159,394	132,908	94,714	71,249	125,874	70,991	56,685	32,426	NA	97,944	NA	46,954	19,061	40.6%
(52)	SITE#13-COLORADO RV NR BALLINGER															
(53)	13	PRECIP	23.74	19.17	23.07	22.46	23.93	25.79	23.87	17.88	21.17	22.86	22.97	11.93	11.54	96.7%
(54)	13	OBS. FLOW	229,805	163,849	86,281	29,987	73,365	50,396	20,903	6,837	8,266	88,827	85,763	81,747	170	0.2%
(55)	13	NAT. FLOW	229,487	209,814	135,100	114,208	187,514	123,838	84,287	44,984	NA	148,951	NA	105,866	26,086	24.6%
(56)	SITE#14-COLORADO RV NR SAN SABA															
(57)	14	PRECIP	27.96	23.10	26.90	27.97	25.55	31.71	29.67	25.53	27.47	27.44	27.55	13.88	17.81	128.3%
(58)	14	OBS. FLOW	857,646	851,874	532,446	492,509	422,158	629,704	376,373	117,775	255,670	568,895	563,854	593,906	50,532	8.5%
(59)	14	NAT. FLOW	945,519	1,009,633	716,002	751,840	679,910	913,043	607,854	255,200	NA	773,767	NA	822,652	134,960	16.4%

(1) "ADJ NF" represents the quantity described as "NAT Flow after Adjustment", which is explained in Section 5.2.2.2.

5.2 GROUP 1 (Study Sites #1, #2, #3)

5.2.1 Study Site #1 – North Concho River near Carlsbad (C7)

There are very few known water rights and no major reservoirs upstream of this site, thus the observed and naturalized flows are essentially the same. The flow information (page D-1 and E-1) shows that the runoff trends for the period before 1958 were substantially different than any of the periods after 1958. This change has been attributed to the proliferation of noxious brush in this watershed by several studies, which is generally believed to have been established at the end of the 1950's as a result of the drought conditions during the 1950's. In addition, it has also been suggested that the different flow trends for these two periods may have been a result of overgrazing in the earlier period before the mid 1950's, followed by less livestock pressures and better management practices in the period after the 1950's drought ended. The research conducted in this study was not able to find any clear, quantifiable data to support either of these assertions nor to determine why the "pre-1950's drought" period shows such significant difference. However, it is recognized that considerable information has been offered in the feasibility studies documented in Section 3.3, as well as other documents summarized in Chapter 4, that does support these conclusions.

Groundwater information for Sterling and Glasscock counties was reviewed for this site. The main aquifer in both counties is the Edwards-Trinity-Plateau aquifer which has numerous monitoring wells, most of which show a steady decline in groundwater levels with some wells in Glasscock county showing as much as 115 feet of decline since 1950 (pages L-2 and L-3). Review of TWDB reported use information from this aquifer for these counties indicated that an average about 38,000 acre-feet per year was used since 1980 in Glasscock county and an average of about 700 acre feet per year was used in Sterling county. Note that the reported use information in the TWDB database does not extend before 1980, thus no reported use information for the Edwards-Trinity-Plateau aquifer in Glasscock or Sterling counties could be analyzed for the period before and immediately after the brush proliferation is said to have begun. It was noted in the aquifer descriptions from the TWDB documentation written in 1995[6] that "in some instances, water levels have declined as a result of increased pumpage. Although historical declines have occurred in the northwest part of the aquifer in Reagan, Upton, Midland, and Glasscock counties as a result of irrigation, none of these areas has experienced declines greater than 20 feet since 1980".

5.2.2 - Study Site #2 – South Concho River at Christoval (C3)

Similar to study site #1, site #2 has very few known water rights upstream and no major reservoirs, thus the observed and naturalized flows are essentially the same (page D-2 and E-2). The flow information indicates the same periods of slight changes in flow trends in the 1950's are similar to those identified for site #1; however, site #1 indicates a higher trend during the 1950's while site #2 indicates a lower trend. This watershed has also been identified as suffering from noxious brush issues. Groundwater information for the counties in the watershed were

[6] Texas Water Development Board, Aquifers of Texas, November 1995, page 21.

reviewed, i.e., Tom Green and Schleicher counties. The main aquifer for this study site's watershed is the Edwards-Trinity-Plateau aquifer, and monitor wells in this aquifer in both counties show a mix of rising and declining elevations over time.

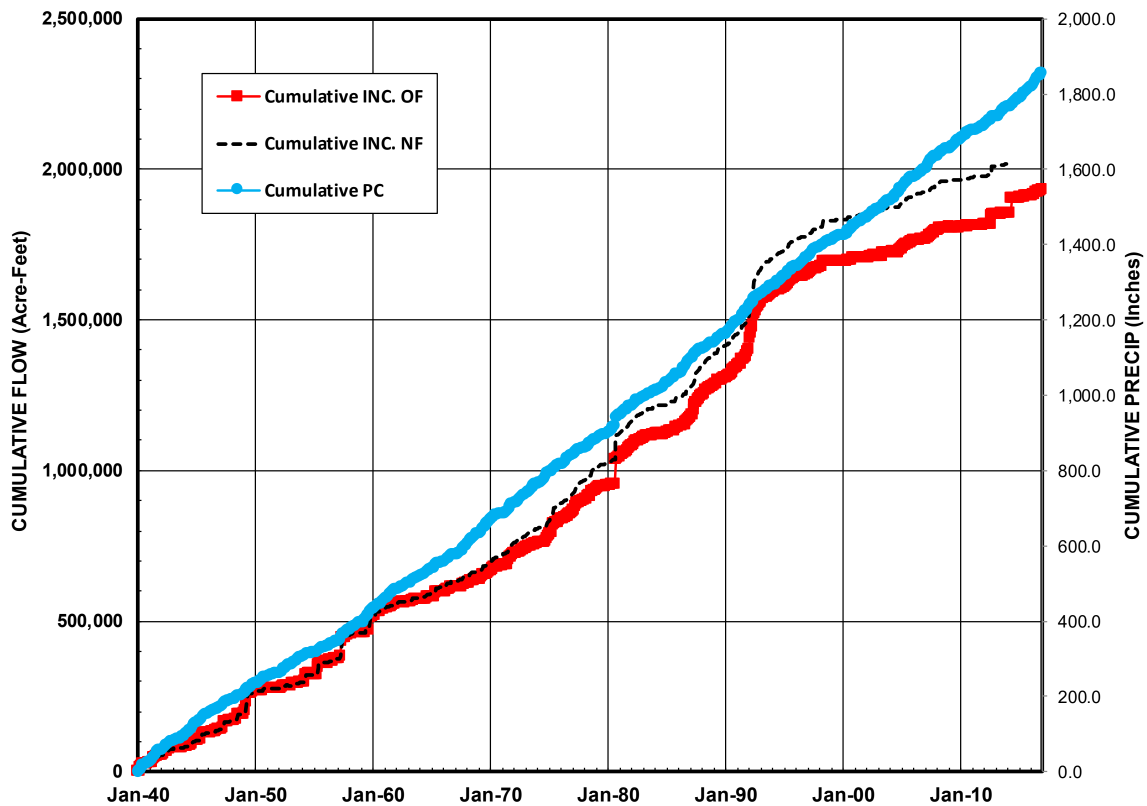
5.2.3 - Study Site #3 – Concho River at Paint Rock (C1)

Study Site #3 has observed streamflows for the entire period of record. In addition, the immediate upstream USGS gage, Concho River at San Angelo (C2), also has observed flows for the entire period of record. Accordingly, this allows for analysis of both the total flow and incremental flow relationships to be examined as explained in Section 2.4.1.

Review of the total flow information for study site #3 (page D-3 and E-3) shows this watershed has significant water rights and 3 major reservoirs upstream of this gage, 2 of the major reservoirs being built within the study period. These major reservoirs' impacts can be seen by noting the difference between the cumulated observed and naturalized flows over time, thus it is clear that observed streamflows were significantly lower in the later period of record, most of which can be attributed to upstream reservoirs and water use by authorized water rights.

Analysis of the incremental flow information provides an opportunity to analyze the observed and naturalized flows rising between the two gages, without the influence of the water rights and reservoirs upstream of the San Angelo gage or the periods of different flow trends noted in study sites #1 and #2, upstream of this study site. Review of this information indicates the following. First, as in the review of the total flows for this site, there is a notable difference between cumulated observed and naturalized flows, which reflects the use of water by water rights in the incremental watershed below the San Angelo streamflow gage. Second, the trends of both traces are fairly consistent for the entire period of record until about 1992. After this, both sets of flows show a downward trend for most of the remainder of the period as demonstrated in Figure 9.

Figure 9
Site #3 incremental flows
between San Angelo and Paint Rock



The Lipan is the predominant aquifer in the counties at and upstream of the study site between Paint Rock and San Angelo (Concho and Tom Green Counties). Review of TWDB reported groundwater use for Tom Green county indicates pumpage from the Lipan aquifer has increased significantly beginning about 1993, with as much as 71,000 acre-feet of water pumped from the aquifer in 1995, up from an average of about 15,000 acre-feet from 1980-1992. A similar percentage of pumpage increase from the Lipan was also noted in Concho county, though the total volumes pumped were significantly less. Review of available groundwater elevation information from the TWDB's groundwater monitoring database shows significant groundwater level declines for wells completed in the Lipan, some declining as much as 70 feet beginning in the early 1990's for Tom Green county (page L-15). Aquifer descriptions from TWDB documentation written in 1995[7] describe the Lipan as follows: "…..groundwater in the Lipan aquifer naturally discharges by seepage to the Concho River and by evapotranspiration where the water table is at or near surface". All of these findings seem to suggest that groundwater declines may have been one of the reasons for the change in flows noted for the periods above. It should also be noted that review of the Lipan aquifer water elevation information indicates that several of the wells that showed declines for the years discussed above have recovered substantially over the last two years.

[7] Texas Water Development Board, Aquifers of Texas, November 1995, page 53.

5.3 GROUP 2 (Study Sites #4, #5, #6)

5.3.1 - Study Site #4 – San Saba River at Menard (E4)

Review of the flow information for this site indicates there are notable differences between observed and naturalized flow (page D-4 and E-4), meaning there is a significant number of water rights utilizing water in the watershed upstream.

Groundwater information for Menard, Schleicher, and Kimble counties were reviewed. The Edwards-Trinity-Plateau, Ellenburger-San Saba, and Hickory aquifers are the predominant aquifers in Menard county while only the Edwards-Trinity-Plateau is significantly used in Schleicher and Kimble counties. Review of monitor well information for Schleicher and Kimble counties showed mixed conclusions, but the Ellenburger-San Saba and Hickory aquifers in Menard county showed declines (pages L-8 and L-13). With regard to these declines, no compelling information was noted in TWDB's aquifer descriptions that would suggest that either aquifer significantly interacts with the nearby watercourses. In addition, the TWDB's summary of the Hickory aquifer's structure appears to suggest that many areas may not be connected to other areas of the Hickory[8].

5.3.2 - Study Site #5 – Brady Creek at Brady (E2)

Review of the flow information for this site shows that there is a notable difference between observed and naturalized flow because of Brady Creek Reservoir's construction in 1963, with very little observed flow at the Brady Creek gage site after Brady Creek Reservoir was constructed (page D-5 and E-5). In addition, similar to study site #1, this site shows a pattern of alternating consistent flow trends (observed as well as naturalized flow) over multi-year periods, interrupted by large rises before another consistent trend begins, with this pattern ending in about 1975 and never repeated again.

Based on review of the TCEQ Dam Safety database described in Chapter 3, it was noted that this small watershed has 44 reservoirs in place (not counting Brady Creek Reservoir), with all but one of these reservoirs being completed within the study period of record (see Table 7 in Chapter 3). In addition, comparing the information for the 43 reservoirs completed after 1940 with the information totaling the number of appropriative water rights in this watershed that are authorized the right to impound water in small reservoirs (see Table 4, Chapter 1) indicates that all of the appropriative water rights listed for this WAM watershed are also represented in the Dam Safety information. Therefore, 43 small reservoirs have been installed upstream of the Brady Creek streamflow gage within the 1940-2016 study period with a total normal storage capacity of 5,268 acre-feet, two of which have appropriative water rights with the remaining 41 reservoirs apparently exempt from water rights permitting requirements.

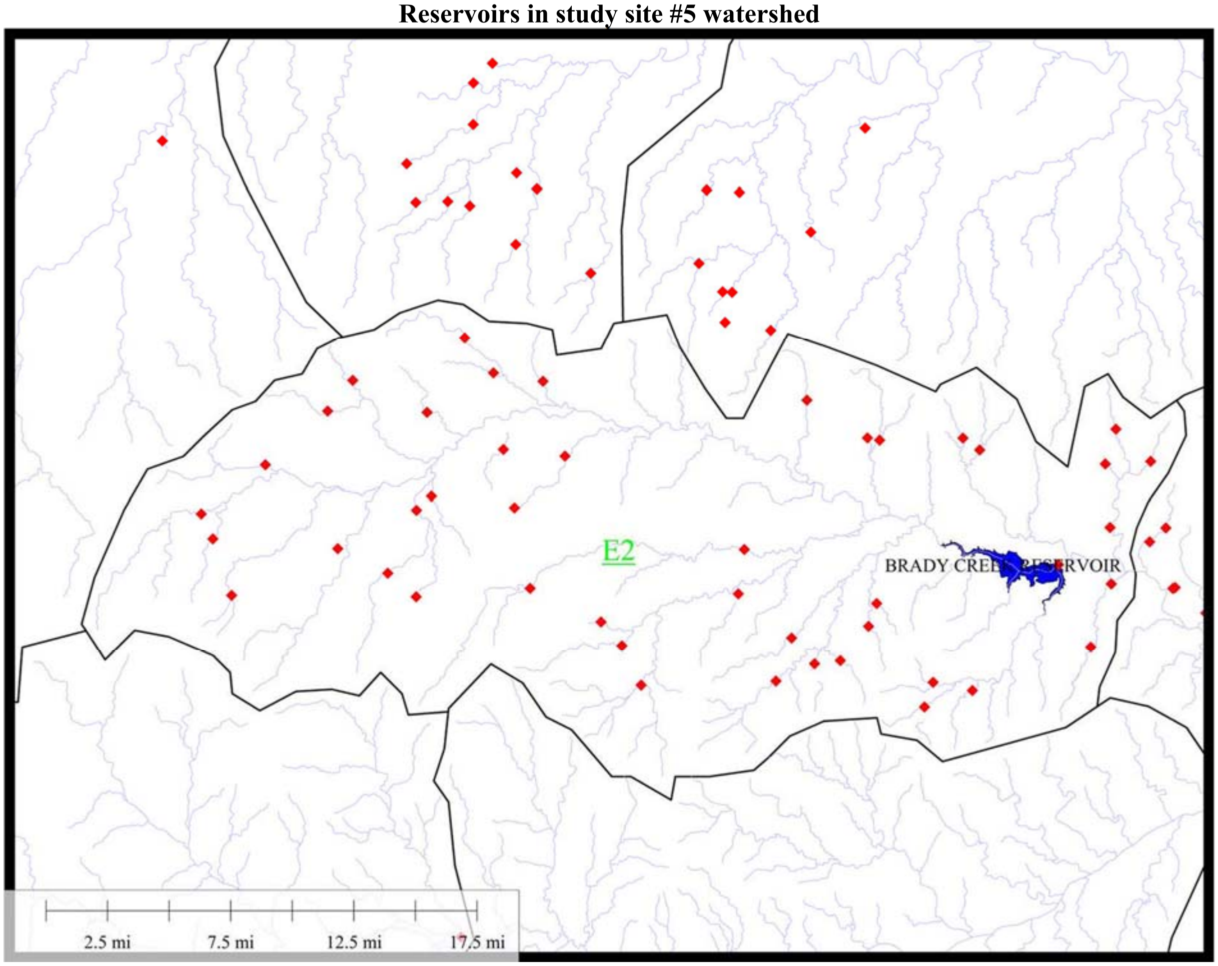
Based on cross review of each of the 43 reservoirs from the Dam Safety database with the NHD waterbody information, it was determined that these 43 reservoirs account for 982 acres of the total 1,605 acres (61%) of water surface area reported for this study site's watershed (Table 9,

[8] Texas Water Development Board, Aquifers of Texas, November 1995, page 36.

Chapter 3). Additional detailed review of this coverage suggests that the majority of the remaining 623 acres of combined water surface area in the NHD coverage appears to include portions of Brady Creek that the coverage identifies as water bodies, as well as numerous other much smaller ponds.

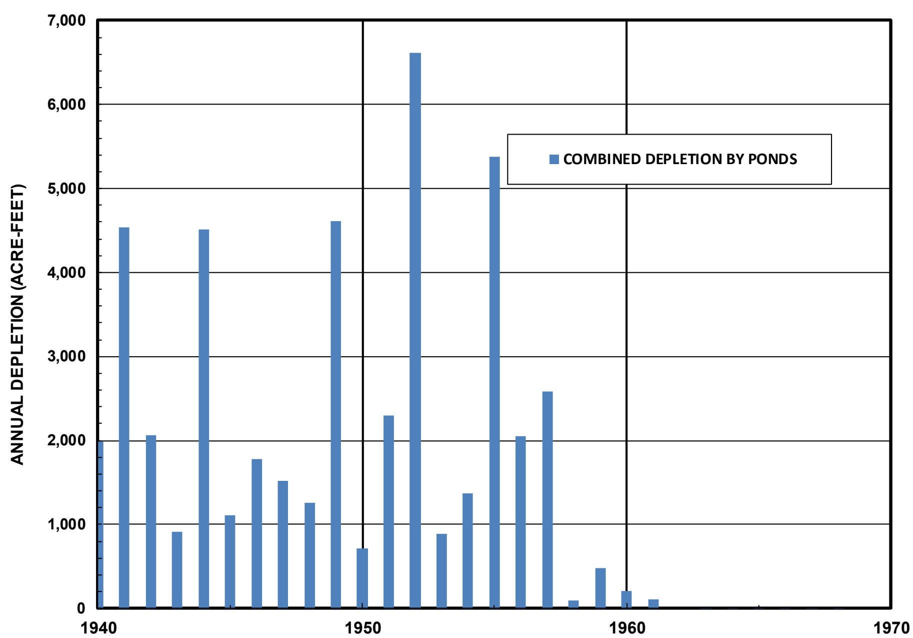
Figure 10 shows the watershed for study site #5 with the red triangles indicating the location of each dam listed in the TCEQ Dam Safety database.

Figure 10
Dam safety database information
Reservoirs in study site #5 watershed



As described in Chapter 3, the flow naturalization process only made adjustments for the impacts of major reservoirs and diversions by appropriative water rights; therefore, the impacts of these 43 smaller reservoirs, which were constructed during the 1940-2016 period, impounding flows are not actually removed from the naturalized flows. Instead, their actual depletions to refill storage, since the time they were constructed, are imbedded in the naturalized flows precisely because they were not removed. Accounting for the impacts of this many reservoirs in the flow naturalization process is an intensive task, requiring considerable information about each reservoir that was not likely readily available. However, for purposes of this study, it has been reasoned that it would be relatively straightforward to impose these reservoirs' impacts on the period **before** they existed using the WAM, which would effectively produce the same level of impact by these reservoirs on the full period of record. To this end, the date of completion, normal water storage capacity, drainage area, and location of each of the reservoirs were taken from the Dam Safety information and a version of TCEQ's WAM model was altered to include the locations of these reservoirs. Because the impacts of each of these reservoirs are already imbedded in the naturalized flows after the period they came into existence, an alternate modeling approach was derived so the model would allow depletions of streamflows for the period before they existed and not allow depletions after the year in which they were constructed (completed). Special WAM input records were developed that allow this operation were created and are presented in **Appendix P**. The modified WAM was executed with these reservoirs assigned a priority date in the model senior to all other rights in the WAM. The resulting simulated flows at study site #5 were extracted immediately after these reservoirs were simulated but before any other WAM activity was encountered, and all other WAM results were disregarded[9]. Figure 11 shows the amount of water these reservoirs would have depleted if they had been in place in the earlier period. It is noted that in one year of the simulation (1952) approximately 6,600 acre-feet of water would have been depleted by these 43 small reservoirs, an amount somewhat larger than the combined capacity of these reservoirs (5,278 acre-feet) due to several refill and evaporation sequences in this single year.

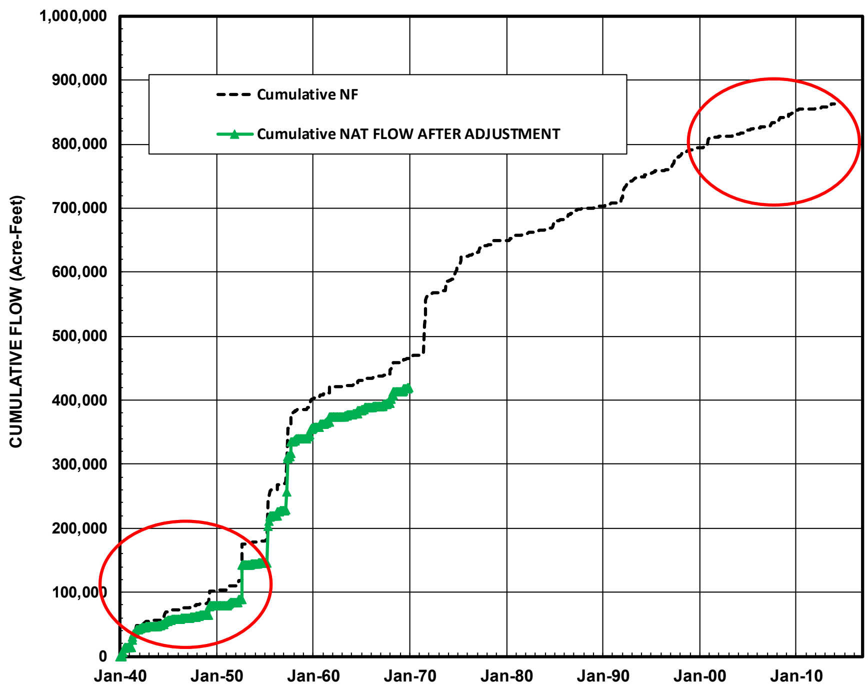
Figure 11
Annual depletions by reservoirs from test approach



[9] It should be noted that the two reservoirs that were authorized under the appropriative water rights system were already in the model and had an authorized diversion amount associated. This diversion amount was set to zero and these two rights were allowed to refill storage in the same manner as the 41 exempt reservoirs.

Figure 12 shows the accumulated result of these adjusted flows compared to the actual naturalized flows before the adjustment.

Figure 12
Brady Creek cumulative flow
with and without adjustment



Note that because the 43 reservoirs described above are imposed in these results for the period they did not actually exist (the period before 1970), the resulting adjusted flow cannot be described as naturalized flow; however, this process does allow the naturalized flows at the Brady Creek gage site to be considered with the impacts of the 43 ponds imposed on the full 1940-2016 period. By comparing the trend of the adjusted naturalized flows (green trace) for the period prior to 1952 with the trend of the true naturalized flows for the most recent period (2001-2013), it is noted that these two trends appear to be similar, apparently because the 43 small reservoirs are now represented in both periods. It should be noted that the remaining water surface area listed in the NHD coverage that is not represented in this test approach (623 acres, or 39.1% of the total water surface are for this study site) cannot be addressed by this approach because information regarding (1) when the water surface areas came into existence, and (2) the water storage capacity of these water surface areas are not known.

The groundwater information for McCulloch and Concho counties also was reviewed. The aquifers in these counties include the Edwards-Trinity-Plateau, Ellenburger-San Saba, and Hickory aquifers for McCulloch county and Edwards-Trinity-Plateau, Hickory, and Lipan aquifers for Concho county. Similar to the case for study site #4, the monitor well information for the aquifers in McCulloch county show declines for the Ellenburger-San Saba and Hickory aquifers (pages L-7 and L-11). In addition, as noted in study site #3, the Lipan aquifer in Concho county shows mixed results.

5.3.3 - Study Site #6 – San Saba River at San Saba (E1)

Study site #6 has observed streamflows for the periods 1/1940 through 9/1993 and 10/1997 through 12/2016. There are two observed flow gages upstream of this location included in the WAM structure, San Saba River near Brady (E3) and Brady Creek at Brady (E2). Incremental flows rising between the two upstream gages and the study site were calculated and reviewed. However, because of missing periods of record in the upstream gages, the valid period of record that could be examined was limited to 7/1979 through 9/1986 and 5/2001 through 12/2016, which was considered to be too limited to be informative.

Review of the total flow information (page D-6 and E-6) indicates there are notable differences between observed and naturalized flow which shows that there is a significant number of water rights utilizing water in the watershed upstream, which includes Brady Creek Reservoir.

Groundwater information was reviewed for San Saba, McCulloch, and Mason counties, with the main aquifers being the Ellenburger-San Saba and Hickory aquifers. San Saba County had overall mixed conditions in the Ellenburger-San Saba aquifer and similar declines in the Hickory aquifer (page L-14) as were noted in Menard county. Mason county also showed some small declines in the Ellenburger-San Saba aquifer (Page L-6).

5.4 GROUP 3 (Study Sites #7, #8)

5.4.1 Study Site #7 – Elm Creek at Ballinger (D3)

Review of the total flow information indicates (1) there are very few water rights using water in the watershed and (2) the trend of both observed and naturalized flows is fairly uniform until 1997, when there is a significant shift through 2013 (page D-7 and E-7).

Groundwater information was reviewed for Runnels and Taylor counties. The main aquifers in these counties are Lipan in Runnels and the Edwards-Trinity Plateau in Taylor. The problems with the Lipan aquifer have been generally described in the section discussing study site #3, however groundwater elevations were noted as being mixed in Runnels county with some wells showing increases while others showing declines. The Edwards-Trinity Plateau aquifer in Taylor county showed steady levels.

5.4.2 - Study Site #8 – Pecan Bayou at Mullin (F2)

Study site #8 has observed streamflows for the period 10/1968 through 12/2016. The Pecan Bayou at Brownwood (F3) streamflow gage is located upstream of this site and is included in the WAM structure. Incremental flows rising between the upstream gage and the study site were calculated and reviewed. However, because of missing periods of record for the upstream gage and this study site gage, the valid period of record that could be examined was limited to 10/1967 through 9/1983, which was considered to be too limited to be informative.

Review of the total flow information for this site indicates there was a significant decline in naturalized flows for the period from the 1970s through the early 1990's, then a sharp decline in about 2007 (page D-8 and E-8). It should be noted that the TECQ Dam Safety database indicates this study site has a large number of small reservoirs located upstream, most of which were completed in the 1960's and 1970's (Table 6, Chapter 3, WAM subwatersheds F3 and F2). This observation is also confirmed by review of the NHD small water body information (Table 8, Chapter 3) for this study site. The process described in Section 5.3.2 to approximate the impacts of unaccounted for small reservoirs was initially considered for this watershed. However, because of the missing period of observed flows for the total and incremental flows at this site, the effort was abandoned.

There are 4 major reservoirs located upstream of this site, three of which were constructed during the study period of record. The effects of these reservoirs along with the other water rights authorized in this watershed can be seen by comparing observed to naturalized flows. Groundwater information was reviewed for Mills, Brown, and Coleman counties. The Ellenbuger-San Saba and Trinity are the main aquifers in this area, and groundwater levels in this area were noted as mixed, with some wells increasing while others showing some small declines.

5.5 GROUP 4 (Study Sites #9, #10)

5.5.1 - Study Site #9 – Llano River at Llano (G1)

Study site #9 has observed streamflows for the entire period record. There are two observed flow gages upstream of this site that are included in the WAM structure, Beaver Creek near Mason (G2) and Llano River near Mason (G3). Incremental flows rising between the two upstream gages and the study site were calculated and reviewed. Because of missing periods of record in the upstream gages, the valid period of record that could be examined was limited to 4/1968 through 4/1993 and 10/1997 through 12/2016.

Review of the total flows (page D-9 and E-9) indicate this study site has a relatively small amount of water rights activities historically using water upstream, and the overall trend of observed and naturalized cumulative flows is very consistent up until about 2007, at which time there is a sharp decline. The incremental flow plot for this site (not presented) shows the same pattern and both plots indicate a large increase in observed flow beginning in about 2015. Groundwater information was reviewed for this site and is addressed under site #10.

5.5.2 - Study Site #10 – Pedernales River near Johnson City (H1)

Study site #10 has observed streamflows for the entire period record. There is one observed flow gage upstream of this site that is included in the WAM structure, Pedernales River near Fredericksburg (H2). Incremental flows rising between the upstream gage and the study site were calculated and reviewed. Because of missing periods of record in the upstream gage, the valid period of record that could be examined was limited to 7/1979 through 4/1993 and 4/1998 through 12/2016, which was considered to be too limited to be informative.

Review of the total flow information (page D-10 and E-10) indicate this study site has a very small amount of water rights activities in place upstream, and the overall trend of observed and naturalized cumulative flows, similar to study site #9, is very consistent up until about 2007, at which time there is a clear decline.

Groundwater information for study sites #9 and #10 were reviewed. The main aquifers in the study site areas include the Ellenburger-San Saba and Hickory aquifers in Llano county, with the same aquifers plus the Edwards-Trinity-Plateau, Marble Falls, and Trinity aquifers in Gillespie county. Some groundwater declines were noted in the Ellenburger-San Saba in Llano county (page L-5) and small declines in the Trinity aquifer in Gillespie county (page L-17).

5.6 GROUP 5 (Study Sites #11, #12, #13, #14)

5.6.1 - Study Site #11 – Colorado River at Colorado City (A1)

Study site #11 has observed streamflows for the period 6/1946 through 12/2016. There are two observed flow gages upstream of this location that are included in the WAM structure, Colorado River near Ira (A3) and Deep Creek near Dunn (A2). However, because of the limited period of observed flows at the Ira site, the resulting incremental watershed with it being ignored would have been essentially the total watershed upstream of study site #11, and thus was not considered to provide additional insight.

Review of the total flow plot information for this study site shows it has one major reservoir upstream (J. B. Thomas) which impacts the observed flows significantly (page D-11 and E-11). It is also noted that the naturalized flow trend shows a generally consistent trend up until 1968, when it shifts down further in 1993, and then again down in 2005.

Groundwater information for Mitchell, Howard, Borden and Scurry counties were reviewed. Dockum, Edwards-Trinity-Plateau, and Ogallala are the dominant aquifers in this area. Of these three, only the Dockum was noted with some declines in Borden County (page L-1).

5.6.2 - Study Site #12 – Colorado River above Silver (B2)

Study site #12 has observed streamflows for the period 9/1967 through 12/2016. There are three observed flow gages upstream of this site that are included in the WAM structure, Beal's Creek near Westbrook (B3), Champion Creek Reservoir near Colorado City (B4), and Colorado River at Colorado City (A1). However, because of the limited period of observed flows at the Champion Creek near Colorado City site, this site was ignored and a special incremental flow was computed quantifying the flow rising between the Beal's Creek near Westbrook gage, the Colorado River at Colorado City gage, and the study site. The valid period of record that could be examined was the same as is defined for the total flow analysis (9/1967 through 12/2016). This incremental plot was reviewed but no information was noted that cannot be seen in the total flow information.

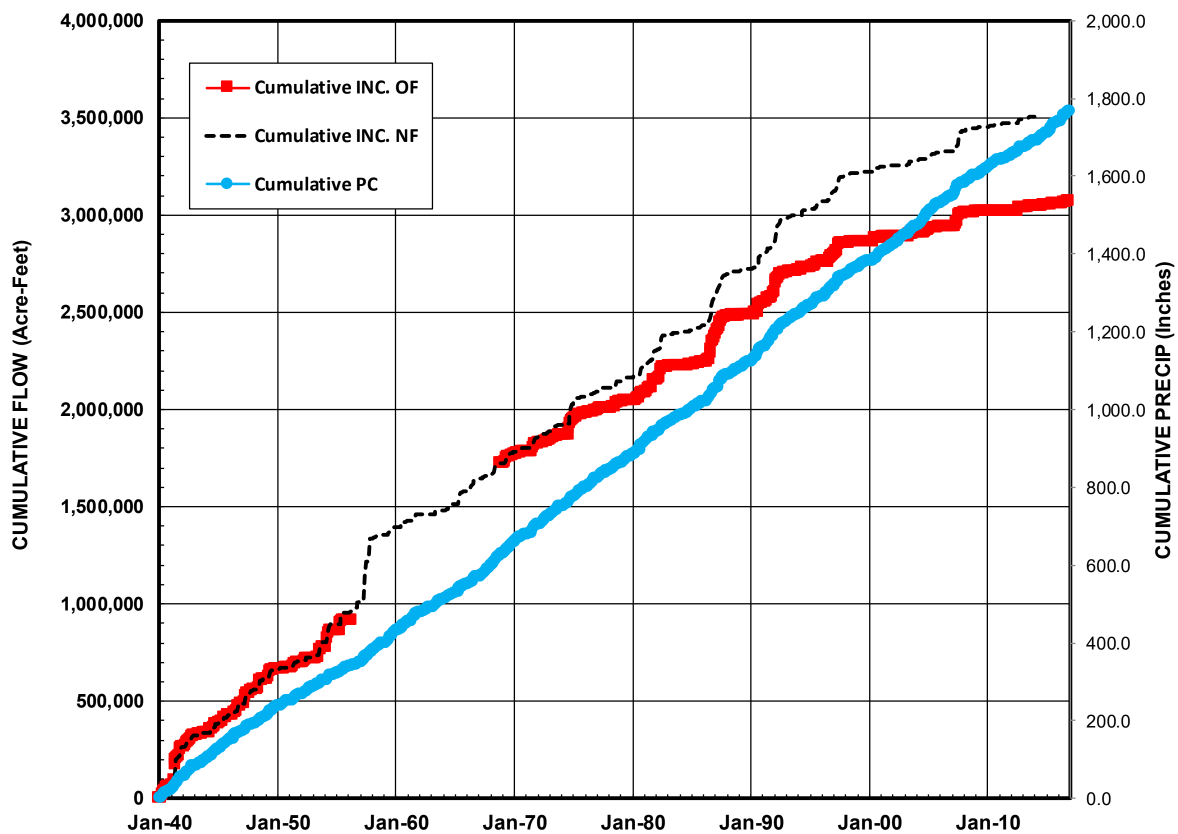
Review of the total flow plot information for this study site (page D-12 and E-12) shows there are seven major reservoirs upstream which impact the observed flows significantly, and most of the changes in naturalized flow trends are similar to that noted for study site #11. It should also be noted that four of these major reservoirs (Natural Dam Lake, Red Draw, Mitchell County Reservoir, Red Draw) were not adjusted for in the naturalized flow process. This issue will be addressed at the end of this chapter.

Groundwater level information was reviewed for the aquifers for this study site in Mitchell, Scurry, Coke, and Nolan counties and no significant declines were noted.

5.6.3 - Study Site #13 – Colorado River near Ballinger (D4)

Study site #13 has observed streamflows for the full period of record. There is one observed flow gage upstream of this site that is included in the WAM structure, Colorado River at Robert Lee (B1). Incremental flows were computed to quantify the flow rising between the Colorado River at Robert Lee gage and the study site. The valid period of record that could be examined was 1/1940 through 4/1956 and 10/1968 through 12-2016. The cumulative mass plot of the incremental flow is presented below as Figure 13. As depicted in the figure, values for the sites' observed incremental flow are missing during the mid 1950's through late 1960's, and the incremental watershed has no major reservoirs. However, it is worthwhile to note that the naturalized flow trace is fairly uniform until the late 1990's when it changes to a lower slope and then maintains the lower slope the remainder of the period.

Figure 13
Site #13 incremental flows
Colorado River near Ballinger



For the total cumulative flow (page D-13 and E-13) this study site has ten major reservoirs upstream which impact the observed flows significantly. As is the case for study site #12, four of these major reservoirs (Natural Dam Lake, Red Draw, Mitchell County Reservoir, Sulphur

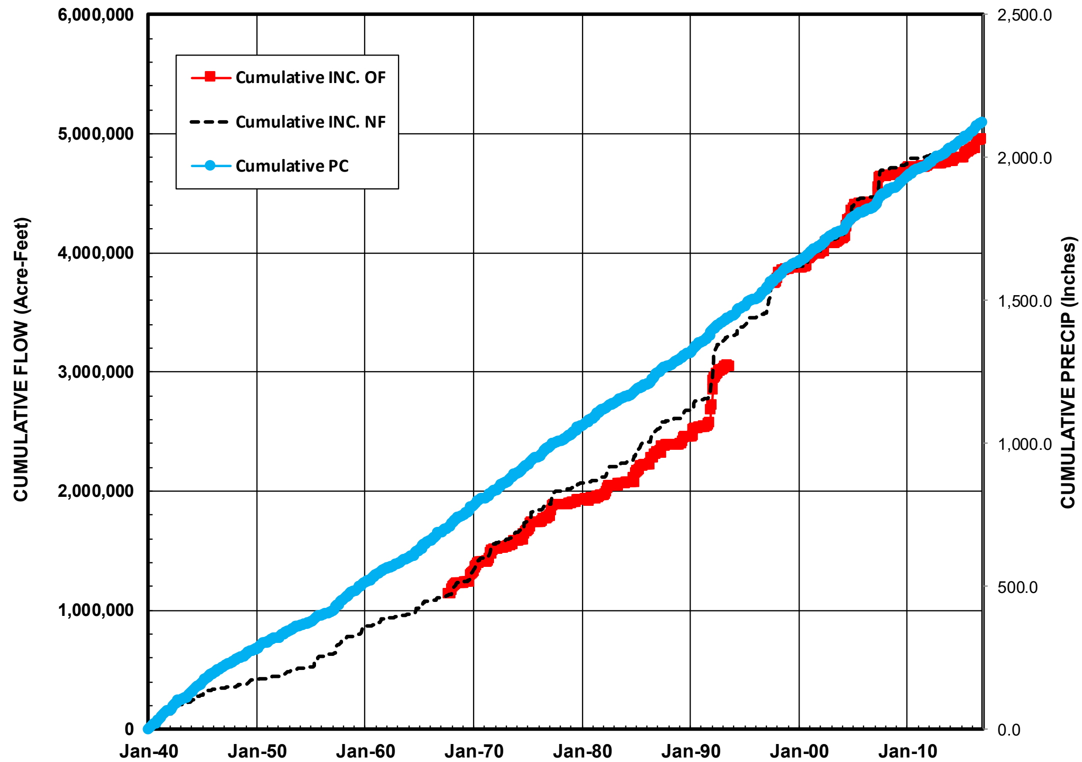
Draw) were not adjusted for in the naturalized flow process and will be addressed at the end of this section. It was noted that the trend of the total naturalized flow for this site has many of the same deflection points that were noted for study sites #11 and #12. However, the incremental flow information presented in Figure 13 does not, which suggests that most of these changes are attributable to the portion of study site #13's watershed that lies upstream of study sites #11 and #12.

Groundwater information for Coke, Nolan, and Taylor counties were reviewed and mixed results were noted. Groundwater information for Runnels county showed mixed results, with the Lipan aquifer being one of the aquifers present in the western edge of Runnels county. Although the review indicated a mixed set of results, it should be noted that the incremental cumulative mass plot for study site #13 (Figure 13) begins to deflect down in about the same years as were noted for study site #3 (1992).

5.6.4 - Study Site #14 – Colorado River near San Saba (F1)

Study site #14 has observed streamflows for the full period of record. There are three observed flow gages upstream of this site that are included in the WAM structure, Colorado River at Winchell (D1), San Saba at San Saba (E1), and Pecan Bayou at Mullin (F2). Incremental flows were computed to quantify the flow rising between these three upstream gages and the study site. The valid period of record that could be examined was 10/1967 through 9/1993 and 10/1997 through 12/2016, which is somewhat limited because of periods of missing data in the upstream gages. The cumulative mass plot of the incremental flow is presented below as Figure 14.

Figure 14
Site #14 incremental flows
Colorado River near San Saba



Note that there are large rises in the traces of both the observed and naturalized flow curves near the end of 1992, which reflect significant inflows due to a large flood. Even with the large flood, the slopes of both lines are nearly the same before and after this flood, until about 2007, when the slope changes significantly. It should also be noted that the observed flow appears to be trending back up in the last 2 years of the period.

For the entire watershed of this study site, there are 20 major reservoirs which impact the observed flows significantly (page D-14 and E-14). As is the case for study sites #12 and #13, four of these major reservoirs (Natural Dam Lake, Red Draw, Mitchell County Reservoir, Sulphur Draw) were not adjusted for in the naturalized flow process and will be addressed at the end of this section.

Groundwater information for the counties in the nearby portion of the watershed for this site are San Saba, McCulloch, Brown and Mills. Groundwater declines for San Saba and McCulloch counties have already been described in previous study site descriptions. Groundwater levels in Brown and Mills were noted as mixed, with some wells indicating rising elevations while others indicating declining elevations.

5.7 Additional Consideration for Select Study Sites on the Colorado River

For study sites 12, 13, and 14, an additional comparison was made of the total flow information. This additional comparison was made of the observed and naturalized flows at each of the 3 study sites after the total observed and naturalized flows at the Beal's Creek near Westbrook (B3) gage were removed. The reason for this was because the four major reservoirs upstream of the Beal's Creek near Westbrook gage were not adjusted for in the naturalized process, meaning that depletions by these reservoirs are imbedded in the naturalized flows that are associated with each location downstream since they were constructed. The date each of the four reservoirs was constructed is indicated below:

- Natural Dam Lake, 1957.
- Red Draw, 1985.
- Michell County reservoir, 1991.
- Sulphur Draw, 1993.

Each of these reservoirs is primarily used for capturing poor quality (high mineral content) water rising in the Beal's Creek watershed in order to prevent these flows from negatively impacting the water quality of water supply reservoirs downstream. As indicated, 3 of these 4 reservoirs were not completed until very late in the period, and since the later period is believed to show declines in naturalized flows for reasons thought to be unrelated to major reservoirs, it was deemed worthy to evaluate the total observed and naturalized flows at each of these downstream study sites without the Beal's Creek watershed included. These comparisons were made, and it was concluded that the exclusion of the observed and naturalized flows rising from the Beal's Creek watershed did not help explain the downward trend of the naturalized flows in the later period of record for study sites #12, 13, and 14. Therefore, the fact that these reservoirs were not considered in the naturalized flow process does not appear to be the reason for the decline in naturalized flows during the later period of record for study sites downstream of this watershed.

6. SUMMARY AND CONCLUSIONS

6.1 Overview

The analyses performed herein were undertaken to explore whether recent observed flows in the Colorado River basin upstream of the Highland Lakes are in fact substantially lower than what has been observed historically, and if so, determine the likely reasons for the disparity. Pursuant to the scope of work and the BBASC's proposed approach for addressing this issue, this work has involved the review of long term rainfall-runoff patterns in the Upper Colorado Basin by analyzing 14 streamflow gage locations in the study area, 10 of which represent most of the of the major tributaries of the Colorado River with the other 4 sites located on the mainstem of the river itself.

Observed flows and precipitation were compiled from available sources, and observed precipitation information was evaluated on a monthly and seasonal basis to determine if long term trends appear to have changed. Results show that while there are some changes over the period of record for some of the information reviewed, long term precipitation volumes at all of the study sites generally indicate a steady to slightly increasing trend over the 1940-2016 study period.

Observed flows were compiled for each of the study sites, and TCEQ's naturalized flows were extracted from the Colorado Basin WAM. Corresponding sets of these flows were used to quantify the extent observed flows may have been historically impacted by streamflow depletions caused by existing appropriative water rights. Comparisons were made of observed precipitation, observed flow, and naturalized flow for each of the study sites. Results from these comparisons indicate that while observed precipitation has been generally steady, observed flow trends at all sites have declined over the period. However, the naturalized flow information indicates that most of the declining trend of observed flows for the majority of the study sites can be attributed to historical water use and the construction of large reservoirs upstream, both of which are associated with existing water rights of record in the study area. These conditions are demonstrated by the cumulative mass and double mass flow graphs presented in Appendices D and E. However, for several of the study sites, it appears that the declines in observed flows were not the result of flow depletions by upstream permitted water rights since few, if any, authorized water rights are authorized upstream. Furthermore, all sites demonstrated some degree of decline in naturalized flows over the period of record, indicating that activities not accounted for in the flow naturalization process could have impacted observed flows, to some degree, over the period of record.

6.2 Other Activities Possibly Impacting Observed Flows

A list was developed of other activities that could have impacted the observed flows over time that are not accounted for in the naturalized flow database. Several of these activities were investigated, with the following four believed to have had some impact on the trend of observed and naturalized flows over the study's period of record:

(1) The proliferation of noxious brush.
(2) The construction of small reservoirs, not accounted for in naturalized flows.
(3) Groundwater use and aquifer water level declines.
(4) Changes in average temperatures and drought conditions.

A limited review of these activities was made and available information was compiled and analyzed. Each of these activities and their possible impacts on observed and naturalized flows are discussed below.

6.2.1 Noxious Brush

Almost all of the study sites are believed to have some degree of noxious brush problems in their contributing watersheds; however, study sites #1, #2, and #3 have had numerous feasibility studies conducted and published that estimate large quantities of streamflow could be recovered if various levels of brush control were implemented. In particular, the North Concho Brush Control Project was completed in the watershed of study site #1, with approximately 340,000 acres of ash juniper and honey mesquite being removed by about 2011. Many experts disagree about the success of substantially increasing flows on a watershed scale by removing brush, and monitoring information after this project was completed only show small gains in streamflow and groundwater elevations. However, several of the years since the project was completed experienced low rainfall, possibly contributing to the inconclusive results and the feasibility reports for this project assumed that aquifers in the area would need to recover substantially before the predicted increases in surface water flow would be realized. The acreage of noxious brush that has been removed from this watershed is significant, amounting to approximately 40% of the total watershed area of the North Concho River. Consequently, the question of whether brush control of this magnitude can substantially increase flow on a watershed basis will likely have to be answered in the coming years, as more data become available to facilitate comparison of observed flows before and after this brush control project was implemented.

6.2.2 Small Reservoirs

Only historical depletions by major reservoirs and diversions for all other appropriative water rights are accounted for in the naturalized flow process. Therefore, at least part of the unexplained decline in naturalized flows certainly could be related to flow impoundments by small reservoirs, which includes reservoirs that exist under both appropriative and exempt water rights. Since the historical impoundment quantities of these small reservoirs were not accounted for when the naturalized flows were developed, the impacts of these small reservoirs are imbedded in the naturalized flows for the later periods after the reservoirs were constructed but they are not reflected in the earlier periods before the reservoirs were constructed, thus the naturalized flows may not be reasonably comparable before and after these reservoirs were constructed. Two different data sources were reviewed that enable some quantification of these small reservoirs, and efforts were conducted to determine the combined quantity of storage, or combined water surface area, attributable to these smaller reservoirs. In addition, an analysis was conducted for study site #5 in an attempt to quantify the extent many of these unaccounted-for small impoundments could have caused the naturalized flows in the later period to be lower than those for the earlier period. The results from these analyses and other published information reviewed suggest that the cumulative effects of numerous small reservoirs in the watersheds upstream of the study sites have impacted the observed and naturalized flows to some degree. However, the body of information available to quantify all of these small reservoirs' location, size and date of completion is very limited and is not sufficient to fully address this issue.

It should be noted that the Colorado River Basin, particularly in the study area of this project, is recognized as being very limited with regard to water being available for appropriation for new water rights. Therefore, it is unlikely there will be many, if any, new water rights granted in the Colorado River Basin in the future, which of course means that the opportunity to construct new small reservoirs subject to the water rights permitting process is likewise very limited. However, there are no such permitting constraints on the construction of exempt reservoirs; thus, it is likely additional exempt reservoirs will continue to be constructed in the watersheds of the study area. In addition, information related to land use changes in the study area indicate an increasing trend of larger parcels of land being subdivided and sold as multiple smaller tracts of land. This change may contribute to even more exempt reservoir construction in the future.

6.2.3 Groundwater Declines

Information from TWDB's monitoring well information was reviewed for most of the counties upstream of each study site. Time series plots of groundwater level variations for numerous wells completed in different aquifers were created and reviewed, and aquifers that had observation information showing declining elevations over the period of record were noted. Most of the study sites showed some amount of groundwater decline associated with aquifers lying within their watersheds. Published information for the aquifers that were identified with declines was reviewed to better understand the significance of the declines. In some cases, the published information indicated that there are known interactions between aquifers and surface water bodies in the area (such as for study site #3). However, in most other cases, the published aquifer information did not specifically address whether such interactions exist or not. Therefore, the extent the declining trends in observed and naturalized flows can be attributed to aquifer water level declines could not be estimated.

6.2.4 Historical Temperature Changes and Drought Conditions

Review of historical temperature information for two stations that contain long term observations indicate that average temperatures have been steadily increasing over much of the period of record of this study. Similarly, examination of NOAA's Palmer Drought Severity Index (PDSI) for the climatic district that covers most of the study area also suggests that the recent drought conditions experienced in 2011 were the most severe (though not the longest in duration) for the entire period of record. In addition, the PDSI information indicates that the period from about 1990 to 2014 has experienced more extreme wet/dry events. This information suggests that some portion of the declines in observed and naturalized flows during the late period of record may be related to the more extreme climatic conditions exhibited by these observations, which likely affected many other factors that influence the soil moisture and runoff that actually produces the observed flows at the study sites.

6.3 Conclusion

All study sites indicate declining trends in observed flows for the study period, 1940-2016, which do not appear to be attributable to historical precipitation quantities. For most of the study sites, the majority of these flow decreases appear to be associated with the utilization of streamflows by authorized water rights of record upstream. However, in several other instances, water use by existing authorized water rights was clearly not the reason for the flow declines. Several other activities were investigated that potentially could have impacted observed flows over time, and attempts were made to quantity and better understand these activities. Research of these topics were conducted and conversations were conducted with knowledgeable representatives in the study area to gain insights. In the end, little useable information was found to be available that could be used to clearly quantify the extent that each of the activities identified actually caused the declines in observed and naturalized flows over the study period.

It should be noted that in all cases but one, the observed flows for last two years of the study period (2015-2016) show an increase in the trend of observed flows. Although the naturalized flow dataset is not yet available for these years, the fact that observed flows have increased will likely translate to an increase in the trend of naturalized flows as well. This increase suggests that many of the decreases noted in the later years before 2015 for many of the study sites may have been related to the most recent severe drought, which began in many areas of the study area in 2007 and lasted until early 2015.

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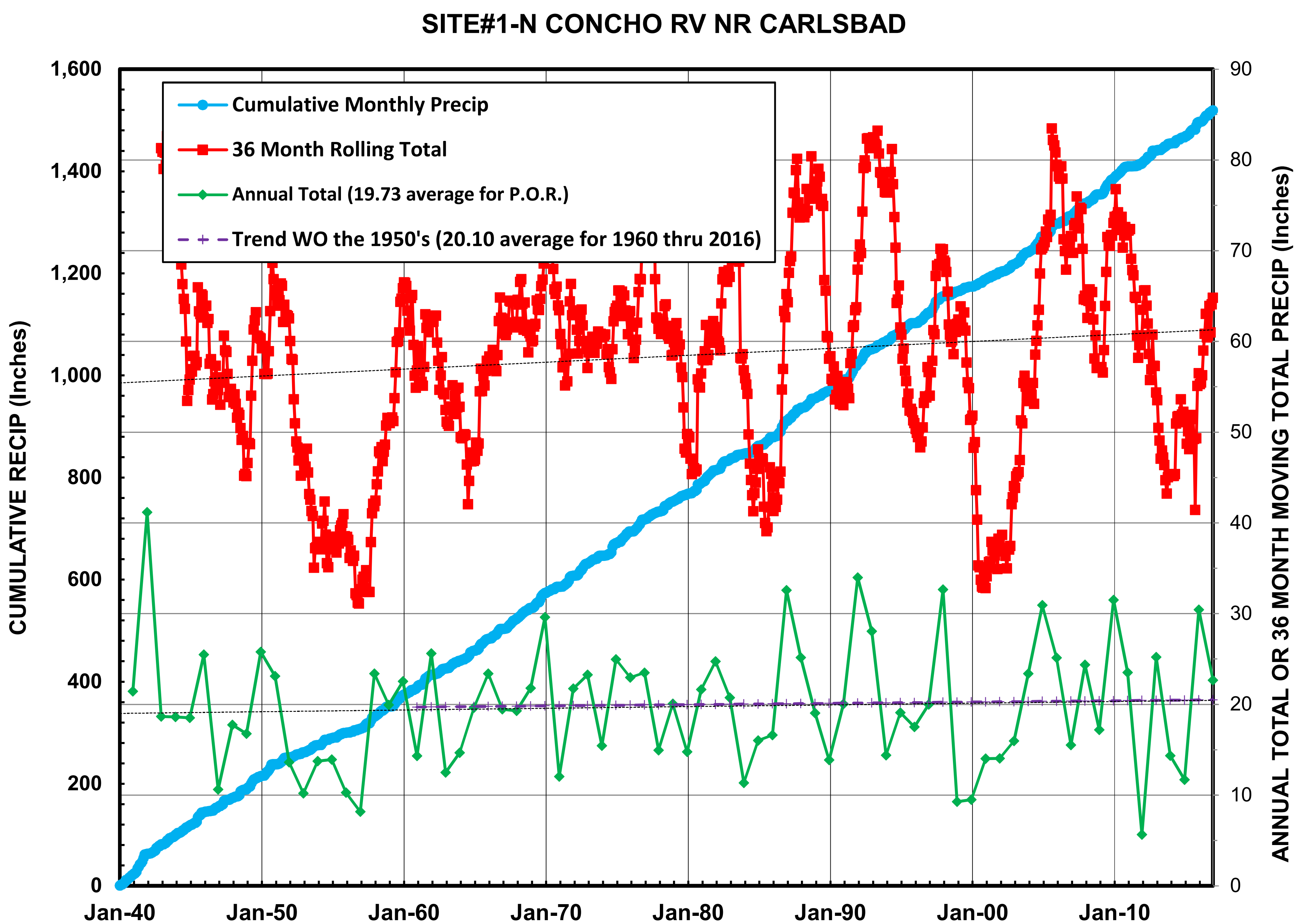
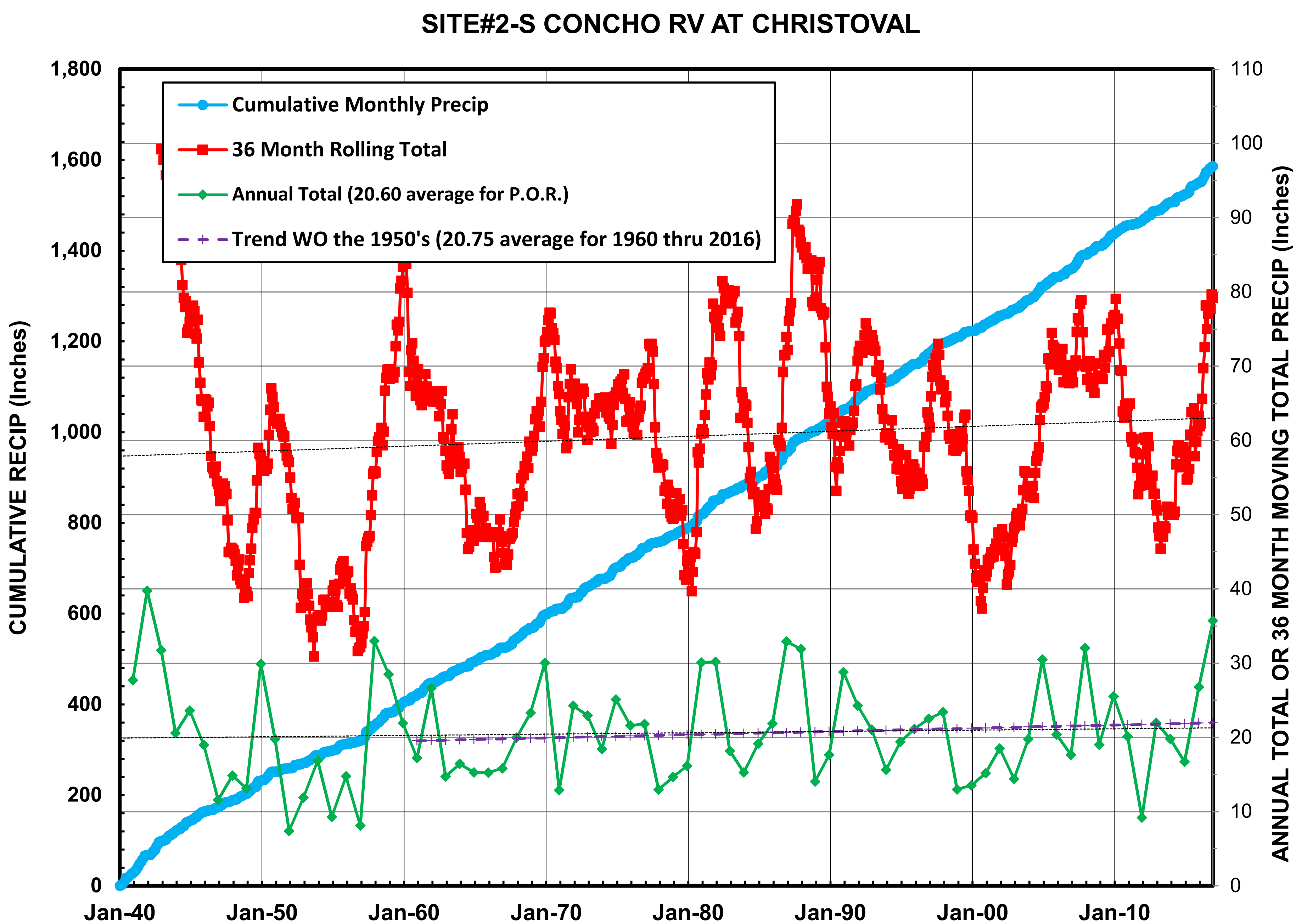
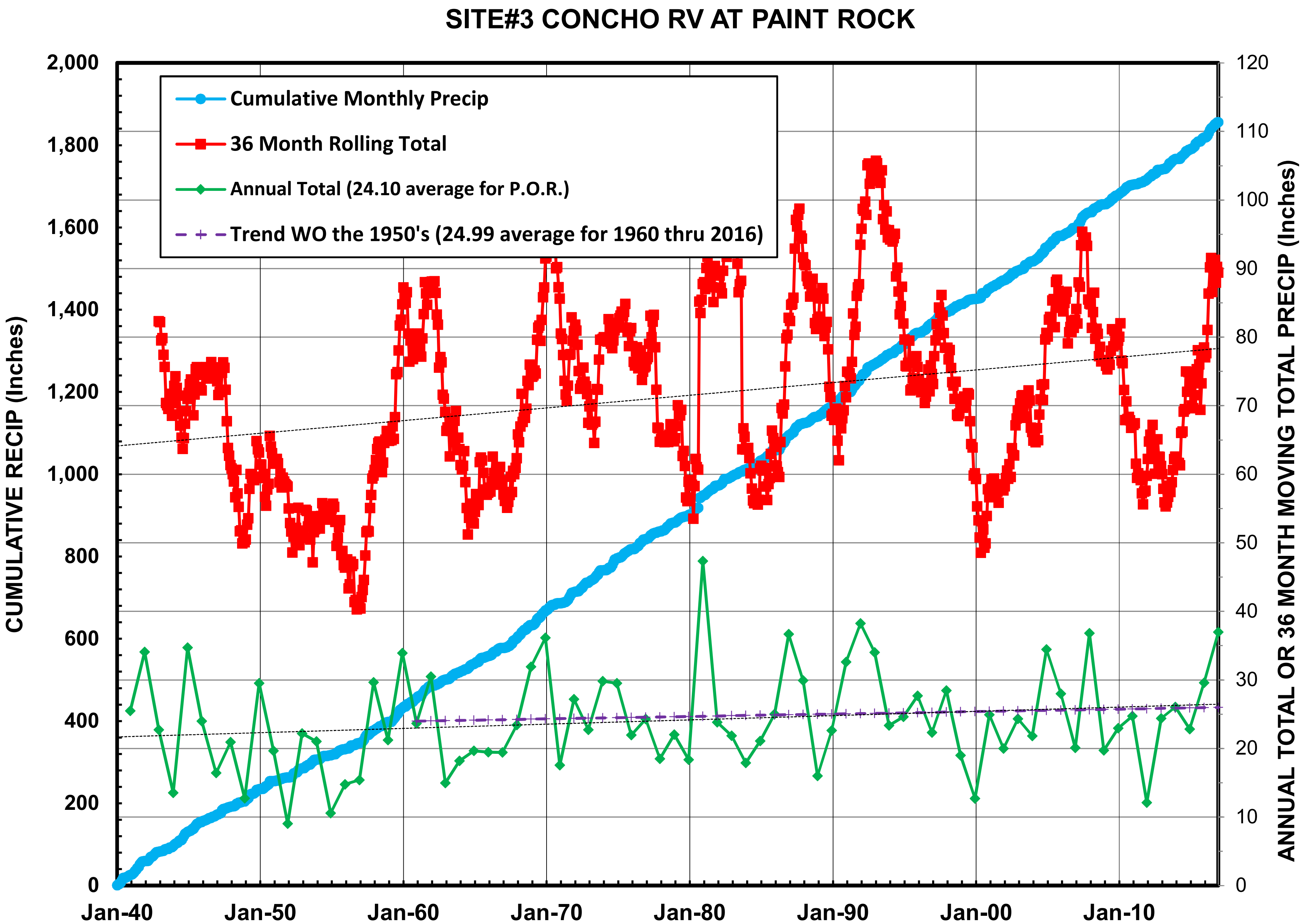
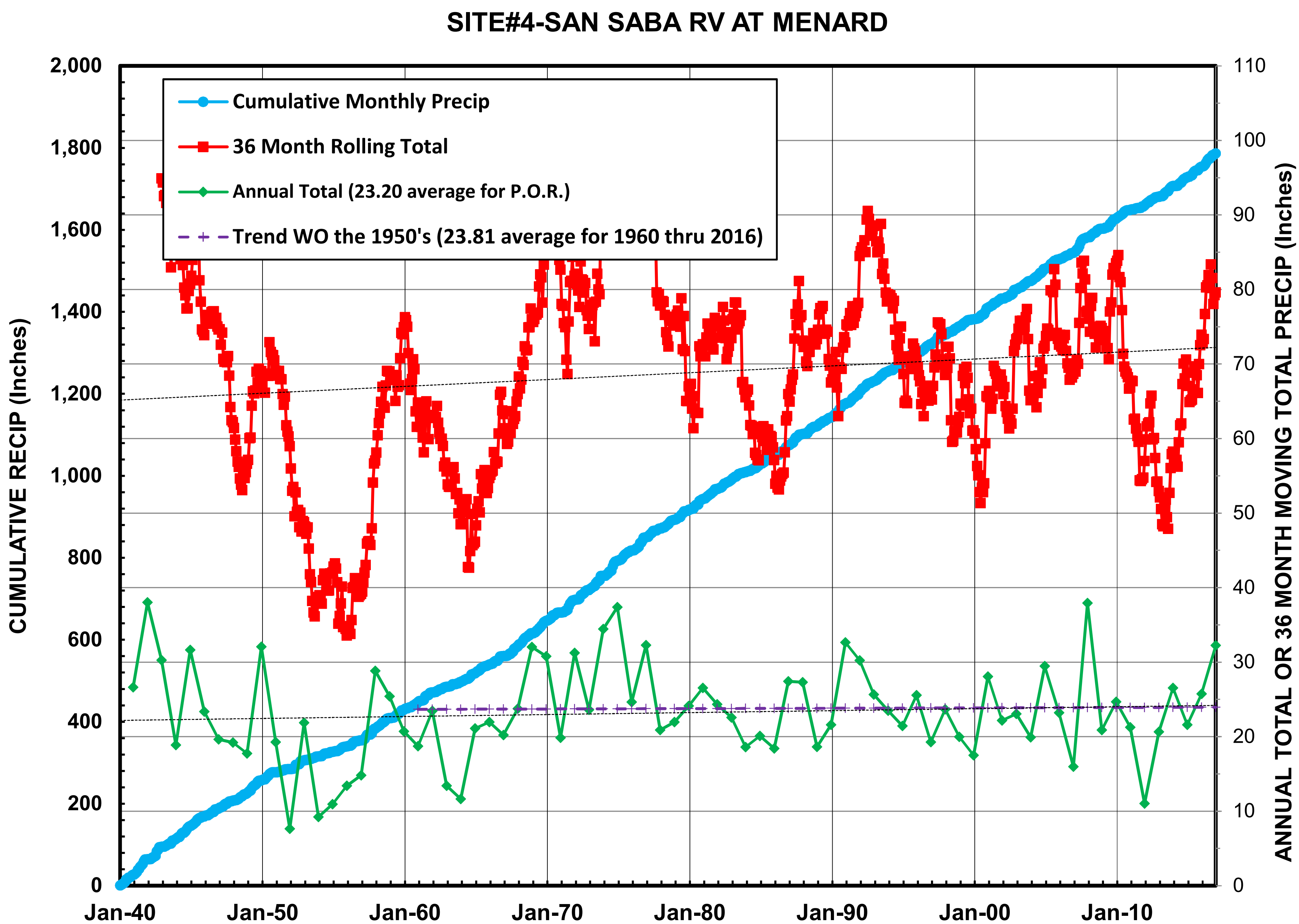
NCDC STATIONS USED TO COMPLETE PRECIPITATION RECORDS				
(1)	(2)	(3)	(4)	(5)
STUDY SITE #	STUDY SITE NAME	NCDC PRECIPITATION STATION NAME	DISTANCE FROM STUDY SITE (MIILES AND DIRECTION)	% OF DAYS USED TO COMPLETE PERIOD OF RECORD
1	N Concho Rv nr Carlsbad, TX	STERLING CITY TX US	26 NW	95.71%
		WATER VALLEY TX US	7 NW	3.85%
		SANATORIUM TX US	1.7 NW	0.33%
		WATER VALLEY 11 NNE TX US	9.4 NE	0.08%
		CASE RANCH 3 S TX US	23.8 W	0.03%
2	S Concho Rv at Christoval, TX	SAN ANGELO MATHIS FIELD TX US	15.8 NNE	73.11%
		CHRISTOVAL TX US	1.3 NE	21.75%
		MERTZON TX US	19.5 WNW	4.15%
		PAINT ROCK 5 NE TX US	41.4 NE	0.99%
		VERIBEST TX US	24 NE	0.00%
3	Concho Rv at Paint Rock, TX	PAINT ROCK 5 NE TX US	4.5 NE	94.17%
		BALLINGER 2 NW TX US	16 NNW	4.90%
		CONCHO PK IVIE RESERVOIR TX US	12 E	0.90%
		ZERO	NA	0.02%
		VERIBEST TX US	20 W	0.01%
4	San Saba Rv at Menard, TX	MENARD TX US	1 S	97.82%
		FORT MCKAVETT TX US	20 WSW	1.61%
		DUNCAN WILSON RANCH TX US	24 WSW	0.35%
		BRADY TX US	30.2 NE	0.16%
		CALLAN TX US	10 NNE	0.02%
		ZERO	NA	0.02%
5	Brady Ck at Brady, TX	BRADY TX US	1 NW	98.42%
		MASON TX US	27 S	0.71%
		MARCO TX US	14 WSW	0.56%
		EDEN TX US	30 W	0.13%
		JOHNSON RANCH TX US	11 NW	0.13%
		ZERO	NA	0.05%
6	San Saba Rv at San Saba, TX	SAN SABA TX US	2 S	64.23%
		SLOAN TX US	12.2 NNW	13.02%
		SAN SABA 7 NW TX US	5.4 NW	12.28%
		SAN SABA 0.4 E TX US	1.1 S	5.34%
		SAN SABA 1.5 E TX US	1.3 SE	3.90%
		RICHLAND SPRINGS TX US	14 WNW	0.93%
		ZERO	NA	0.20%
		SAN SABA 7.3 ENE TX US	6.4 ENE	0.11%
7	Elm Ck at Ballinger, TX	WINGATE TX US	22 NW	53.61%
		TALPA TX US	14.6 E	22.07%
		BALLINGER 2 NW TX US	1.8 WSW	11.59%
		NOVICE 1 E TX US	25 NE	10.60%
		PAINT ROCK 5 NE TX US	16.5 S	1.32%
		LAWN TX US	28.7 ENE	0.55%
		WINTERS 9 NNE TX US	24 NNW	0.22%
		ZERO	NA	0.04%

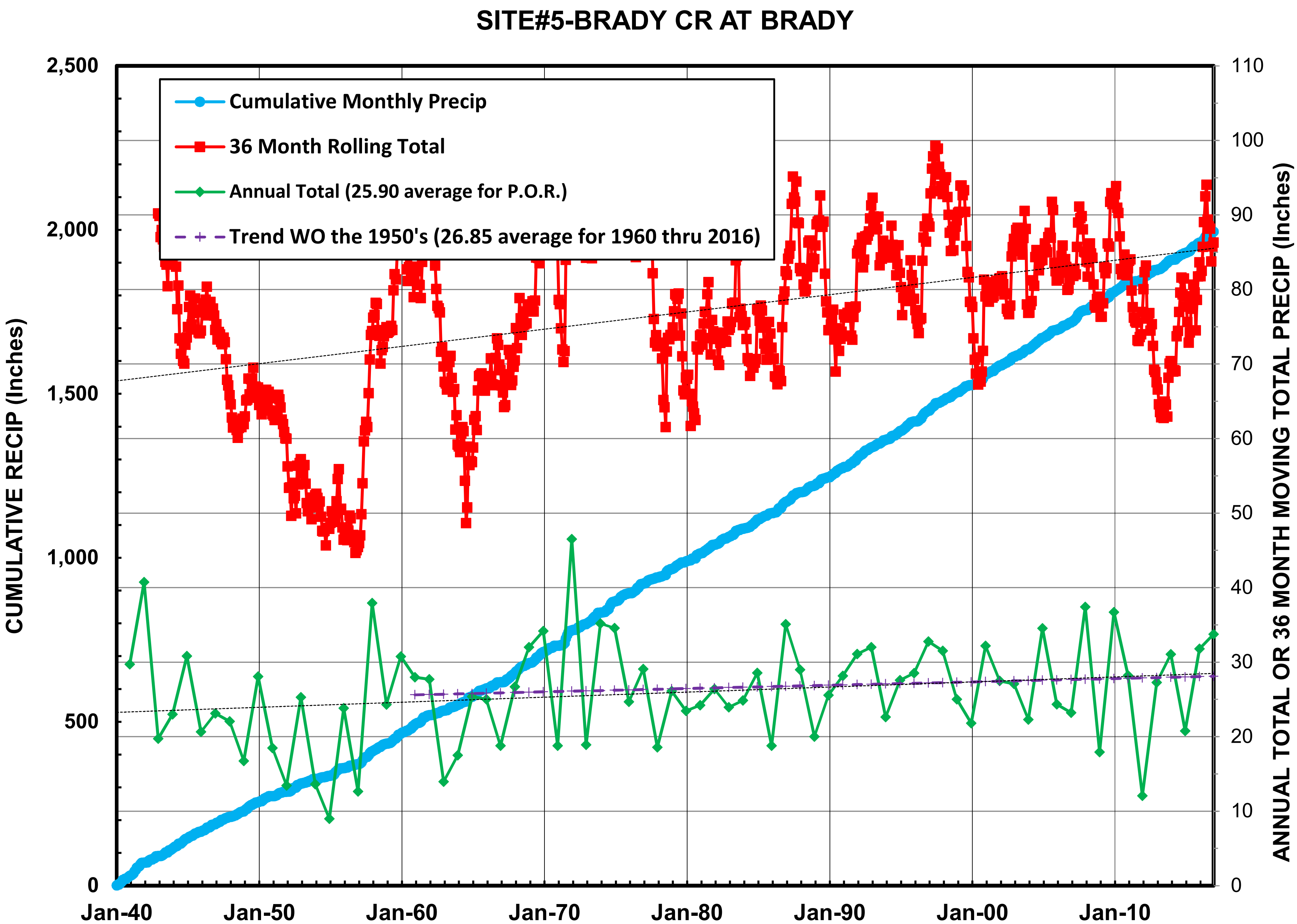
NCDC STATIONS USED TO COMPLETE PRECIPITATION RECORDS				
(1)	(2)	(3)	(4)	(5)
STUDY SITE #	STUDY SITE NAME	NCDC PRECIPITATION STATION NAME	DISTANCE FROM STUDY SITE (MIILES AND DIRECTION)	% OF DAYS USED TO COMPLETE PERIOD OF RECORD
8	Pecan Bayou nr Mullin, TX	MULLIN TX US	6.4 NE	67.76%
		GOLDTHWAITE 1 WSW TX US	10 SE	21.39%
		MULLIN 3.9 WSW TX US	1.2 NE	10.15%
		BROWNWOOD 2 ENE TX US	19.5 NW	0.71%
9	Llano Rv at Llano, TX	LLANO TX US	1SE	99.22%
		MASON TX US	33 W	0.38%
		JAMES RIVER RANCH TX US	45 WSW	0.24%
		ZERO	NA	0.10%
		LLANO 0.5 ESE TX US	.05 SE	0.07%
		LLANO 9.2 NNW TX US	9.2 NW	0.00%
10	Pedernales Rv nr Johnson City, TX	JOHNSON CITY 2 N TX US	0.5 SW	60.21%
		BLANCO TX US	13 S	38.99%
		FREDERICKSBURG TX US	30 W	0.59%
		HYE TX US	10.5 WSW	0.21%
11	Colorado Rv at Colorado City, TX	COLORADO CITY TX US	1.2 E	64.97%
		KNAPP 2 SW TX US	22 NW	29.24%
		SNYDER TX US	22 NW	5.42%
		BIG SPRING 5 NE TX US	31 W	0.33%
		GAIL TX US	43 NW	0.02%
		ZERO	NA	0.01%
		LAKE COLORADO CITY TX US	4.4 SW	0.01%
12	Colorado Rv abv Silver, TX	STERLING CITY TX US	19.1 SW	57.49%
		STERLING CITY 8 NE TX US	10.75 SW	37.45%
		SILVER TX US	1 N	4.00%
		LAKE COLORADO CITY TX US	24 NNW	0.73%
		OAK CREEK LAKE TX US	26 E	0.10%
		COLORADO CITY TX US	26.5 NNW	0.15%
		ZERO	NA	0.08%
13	Colorado Rv nr Ballinger, TX	BALLINGER 2 NW TX US	3.5 NE	97.00%
		PAINT ROCK 5 NE TX US	16 S	2.96%
		ZERO	NA	0.03%
		WINGATE TX US	24 NNW	0.01%
14	Colorado Rv nr San Saba, TX	RED BLUFF CROSSING TX US	1 W	85.36%
		GOLDTHWAITE 1 WSW TX US	15.4 N	11.16%
		SAN SABA TX US	8 WSW	3.37%
		LOMETA TX US	9.7 E	0.11%

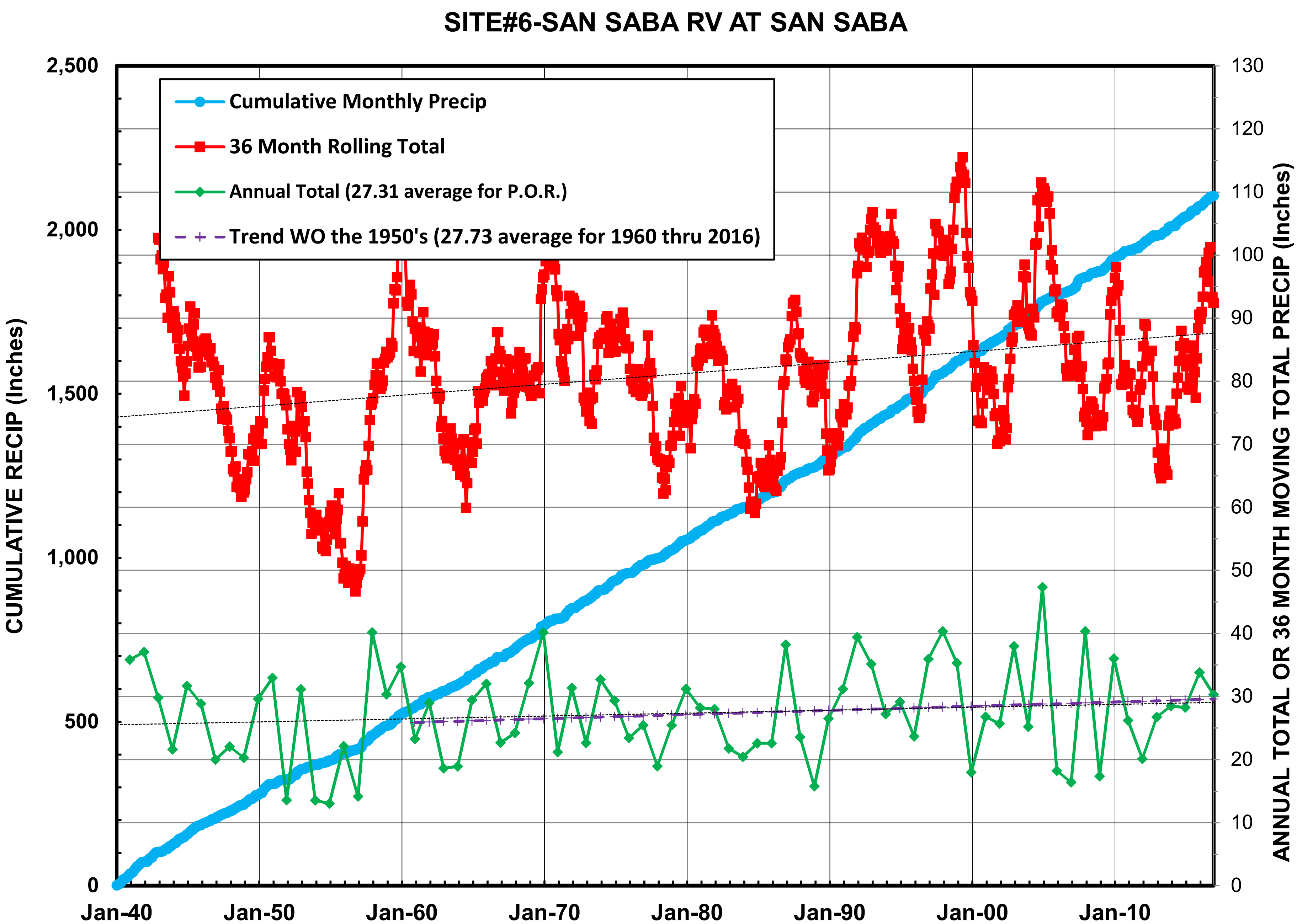

SITE#1-N CONCHO RV NR CARLSBAD
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (19.73 average for P.O.R.)
Trend WO the 1950's (20.10 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
1,600
1,400
1,200
1,000
800
600
400
200
0
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

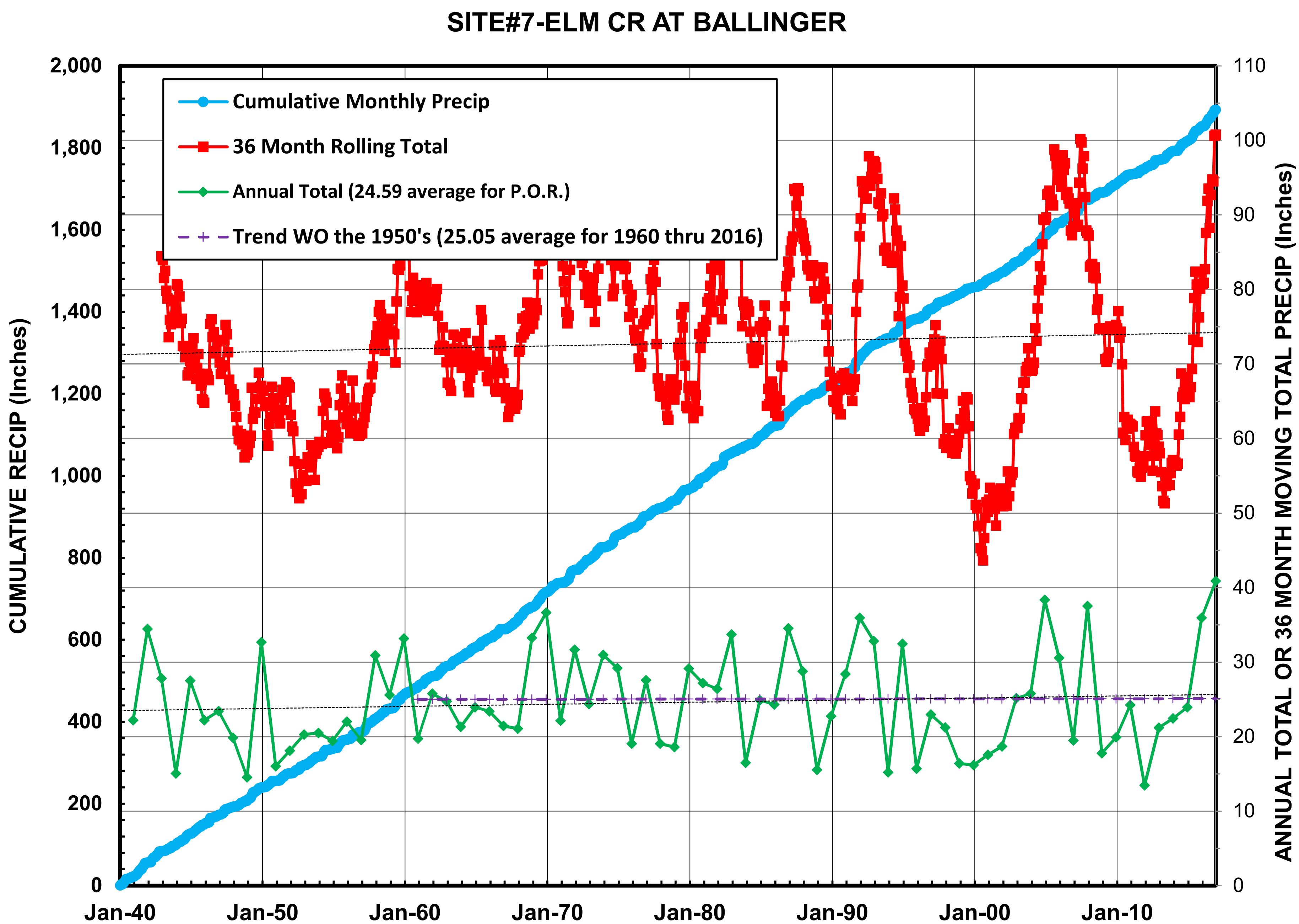

SITE#2-S CONCHO RV AT CHRISTOVAL
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (20.60 average for P.O.R.)
Trend WO the 1950's (20.75 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

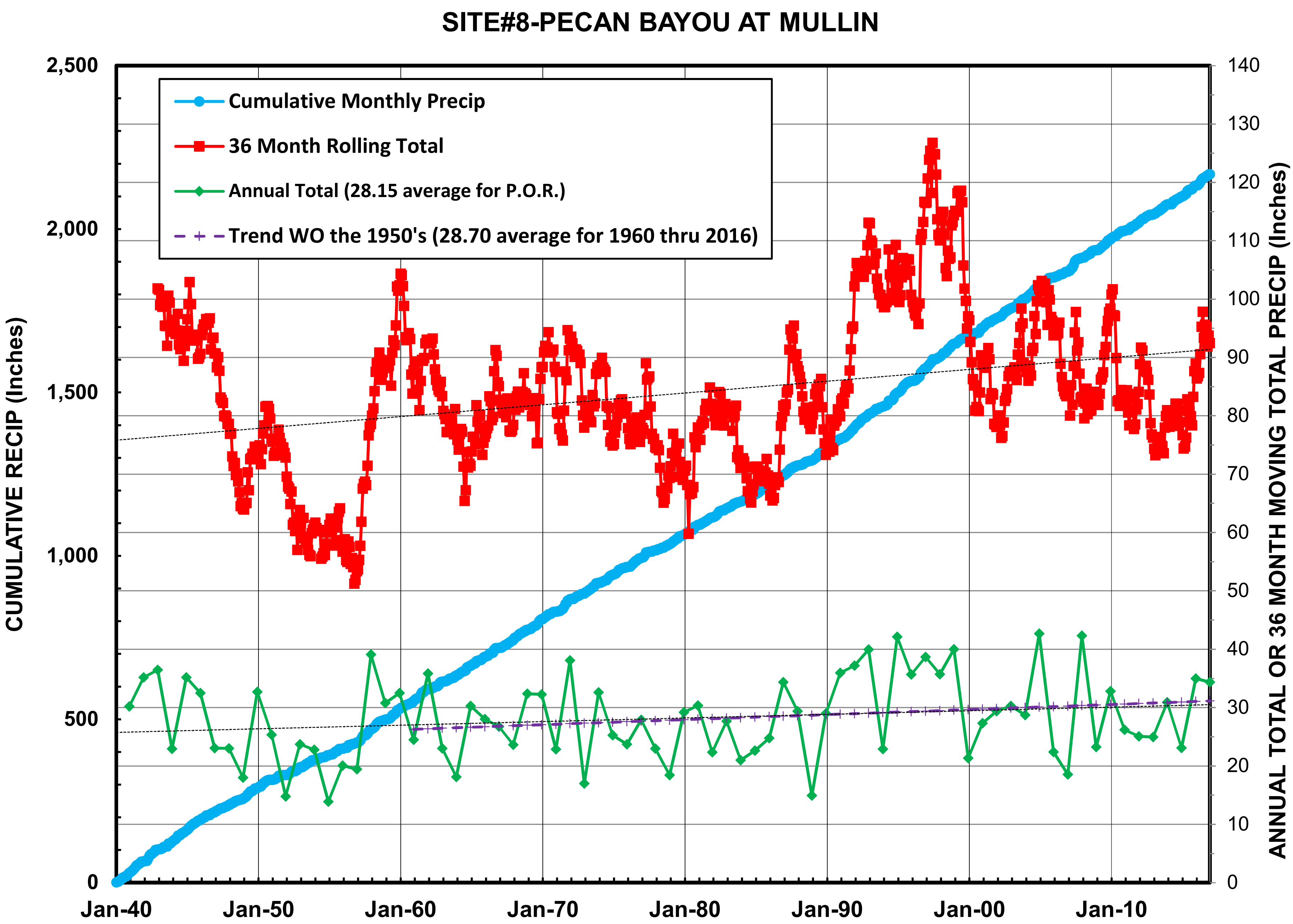

SITE#3 CONCHO RV AT PAINT ROCK
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (24.10 average for P.O.R.)
Trend WO the 1950's (24.99 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

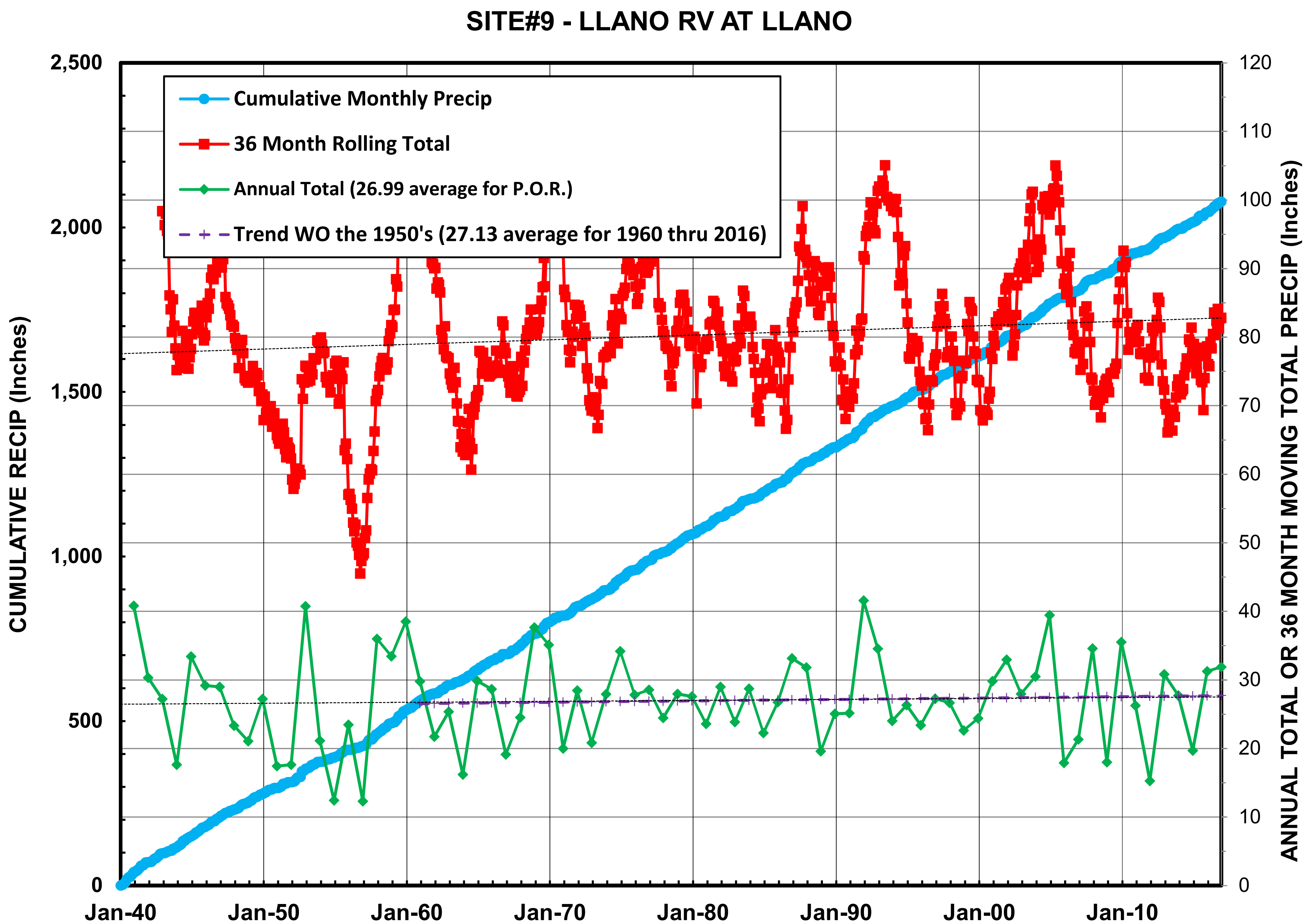

SITE#4-SAN SABA RV AT MENARD
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (23.20 average for P.O.R.)
Trend WO the 1950's (23.81 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

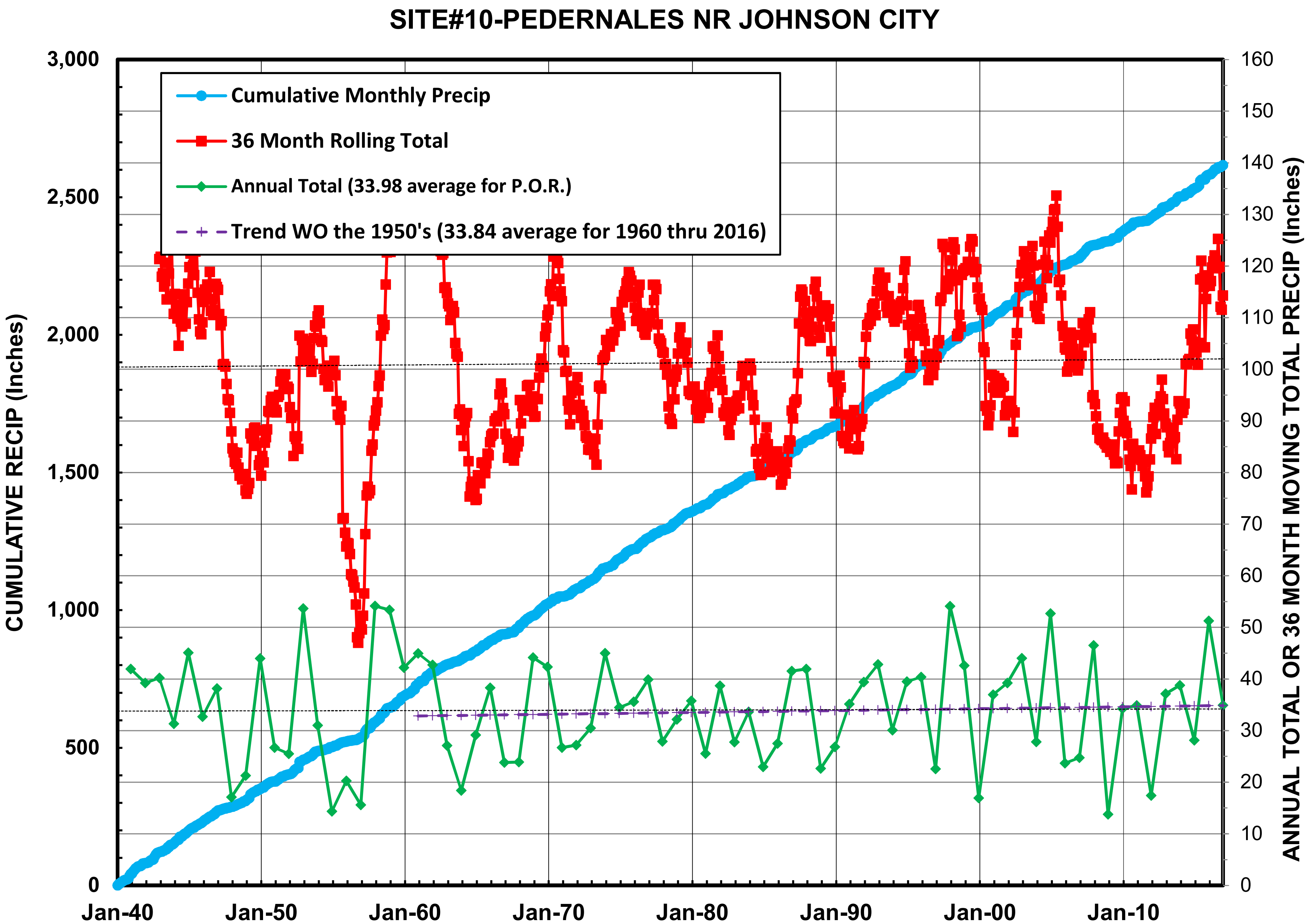

SITE#5-BRADY CR AT BRADY
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (25.90 average for P.O.R.)
Trend WO the 1950's (26.85 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,500
2,000
1,500
1,000
500
0
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

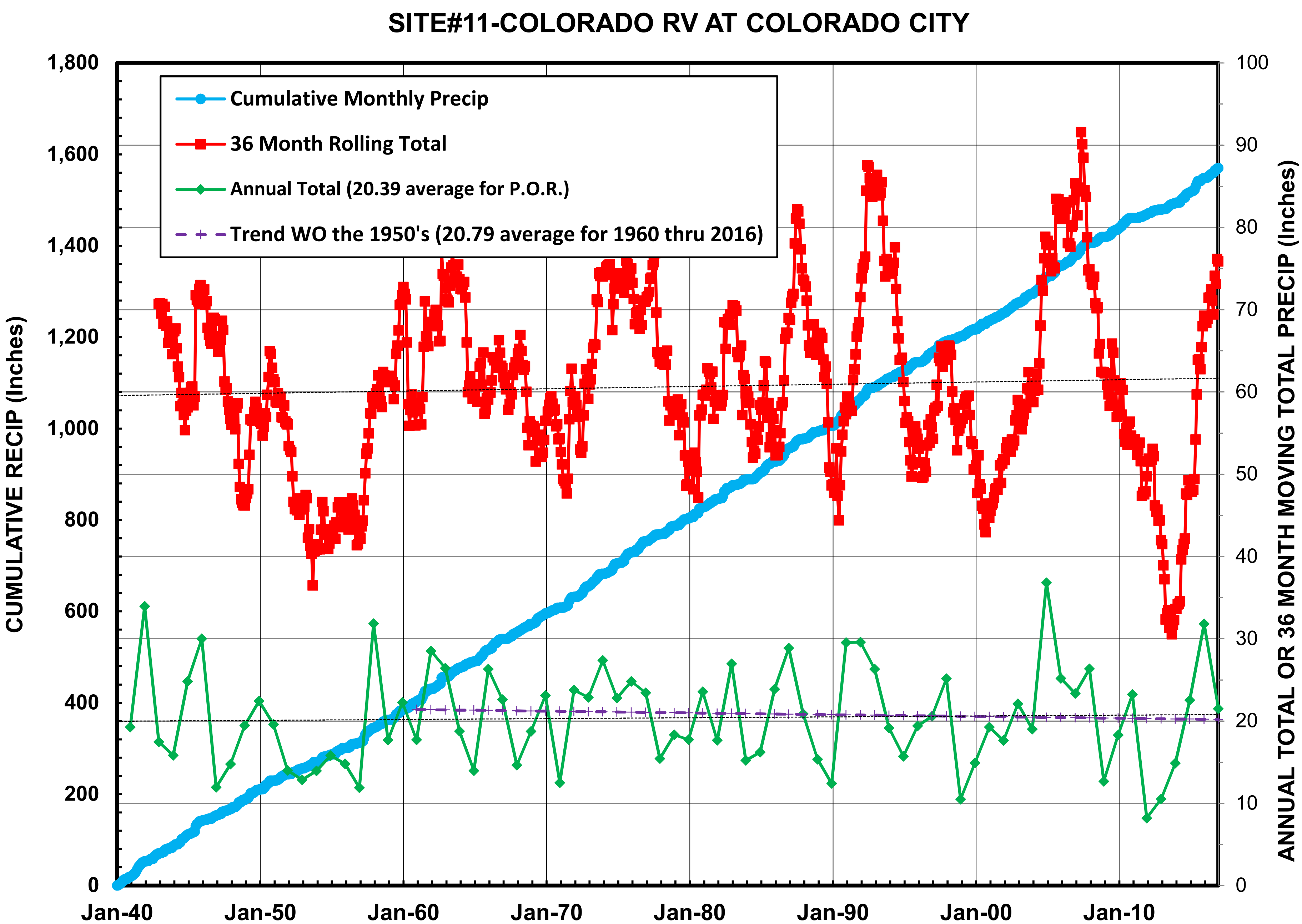

SITE#6-SAN SABA RV AT SAN SABA
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (27.31 average for P.O.R.)
Trend WO the 1950's (27.73 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,500
2,000
1,500
1,000
500
0
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

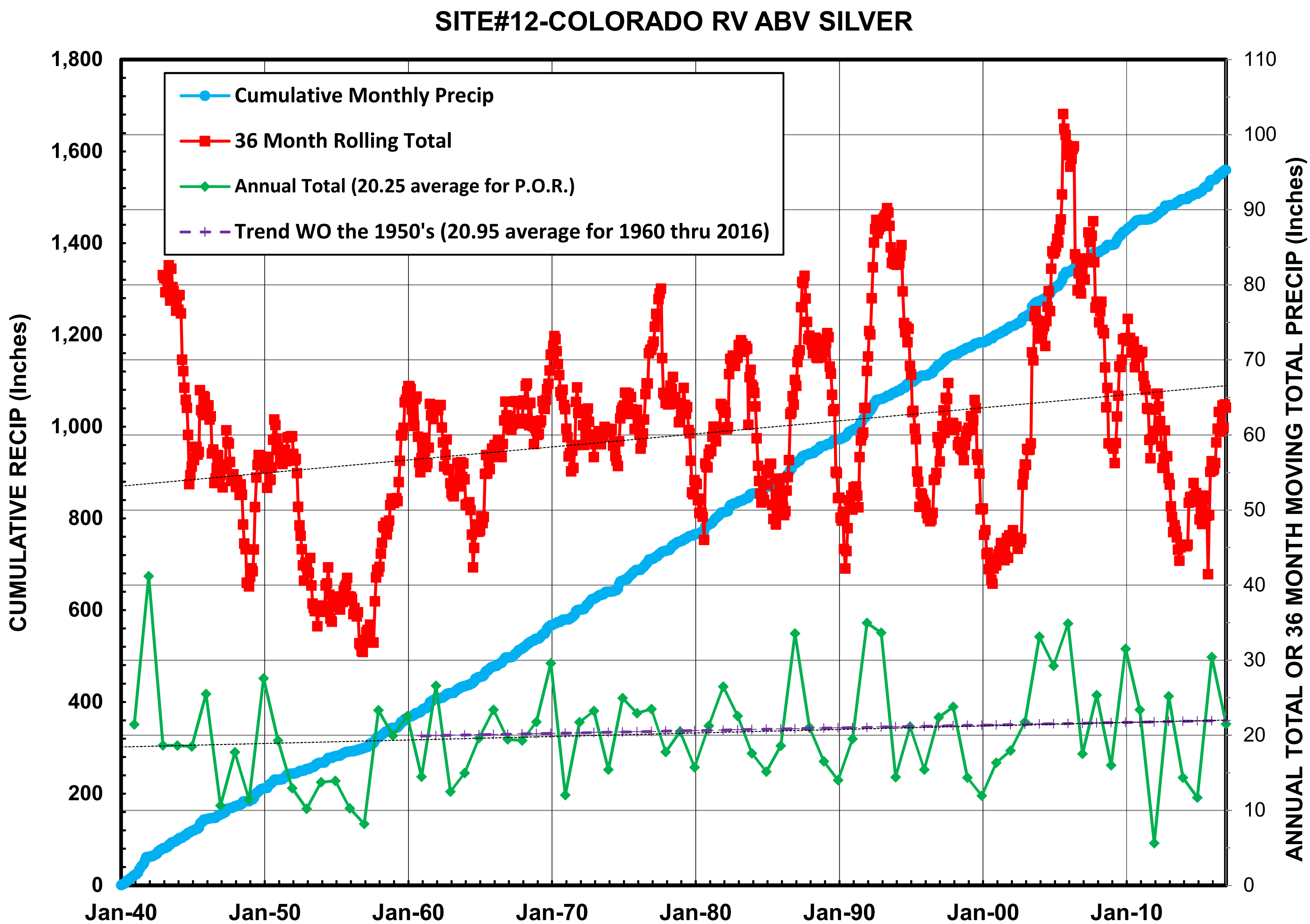

SITE#7-ELM CR AT BALLINGER
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (24.59 average for P.O.R.)
Trend WO the 1950's (25.05 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

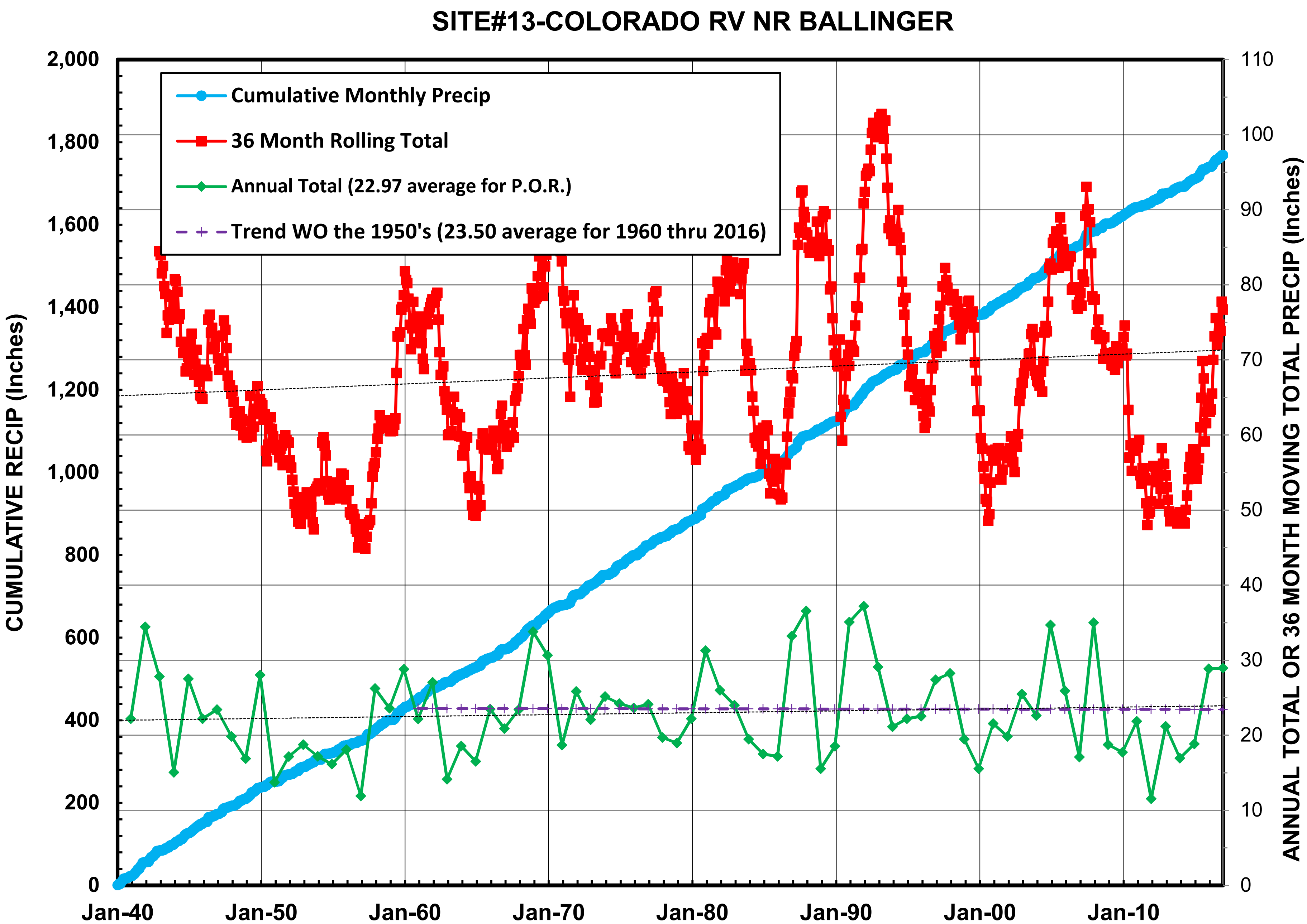

SITE#8-PECAN BAYOU AT MULLIN
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (28.15 average for P.O.R.)
Trend WO the 1950's (28.70 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,500
2,000
1,500
1,000
500
0
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

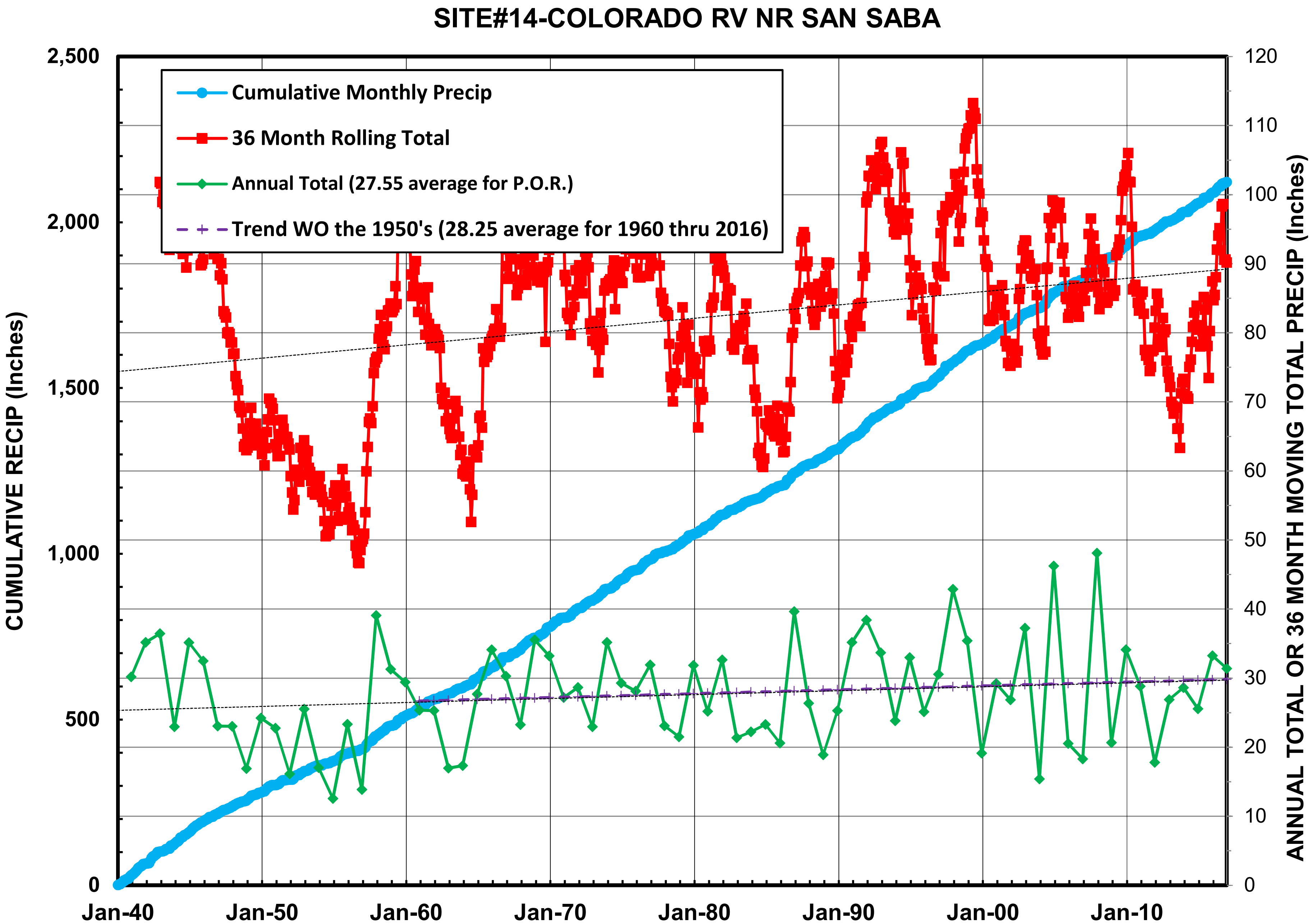

SITE#9 - LLANO RV AT LLANO
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (26.99 average for P.O.R.)
Trend WO the 1950's (27.13 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,500
2,000
1,500
1,000
500
0
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


SITE#10-PEDERNALES NR JOHNSON CITY
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (33.98 average for P.O.R.)
Trend WO the 1950's (33.84 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
3,000
2,500
2,000
1,500
1,000
500
0
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


SITE#11-COLORADO RV AT COLORADO CITY
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (20.39 average for P.O.R.)
Trend WO the 1950's (20.79 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
0
10
20
30
40
50
60
70
80
90
100
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


SITE#12-COLORADO RV ABV SILVER
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (20.25 average for P.O.R.)
Trend WO the 1950's (20.95 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


SITE#13-COLORADO RV NR BALLINGER
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (22.97 average for P.O.R.)
Trend WO the 1950's (23.50 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


SITE#14-COLORADO RV NR SAN SABA
Cumulative Monthly Precip
36 Month Rolling Total
Annual Total (27.55 average for P.O.R.)
Trend WO the 1950's (28.25 average for 1960 thru 2016)
CUMULATIVE RECIP (Inches)
ANNUAL TOTAL OR 36 MONTH MOVING TOTAL PRECIP (Inches)
2,500
2,000
1,500
1,000
500
0
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

PERIOD OF RECORD AVAILABLE FOR INCREMENTAL FLOW ANALYSIS

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
STUDY SITE WATERSHED INFORMATION					IMMEDIATE UPSTREAM WATERSHED INFORMATION		VALID PERIOD FOR INCREMENTAL ANALYSIS
STUDY SITE NUMBER	WATERSHED ID	STATION_NM	USGS NUMBER	RECORD OF OBSERVED FLOW	MAP ID	RECORD OF OBSERVED FLOW	
3	C1	Concho Rv at Paint Rock, TX	08136500	1/1940-12/2016	C2	1/1940-12/2016	1/1940-12/2016
6	E1	San Saba Rv at San Saba, TX	08146000	1/1940-9/1993; 10/1997-12/2016	E2	1/1940-9/1986; 4/2001-12/2016	7/1979-9/1986; 5/2001-12/2016
					E3	7/1979-9/1993; 10/1997-12/2016	
8	F2	Pecan Bayou nr Mullin, TX	08143600	10/1967-12/2016	F3	1/1940-9/1983	10/1967-9/1983
9	G1	Llano Rv at Llano, TX	08151500	1/1940-12/2016	G2	8/1963-12/2016	4/1968-4/1996; 10/1997-12/2016
					G3	4/1968-4/1996; 10/1997-12/2016	
10	H1	Pedernales Rv nr Johnson City, TX	08153500	1/1940-12/2016	H2	7/1979-4/1993; 4/1998-12/2016	7/1979-4/1993; 4/1998-12/2016
11	A1	Colorado Rv at Colorado City, TX	08121000	6/1946-12/2016	A3	10/1947 - 9/1952; 10/1958-9/1989 [1]	4/1953-9/1986; 8/2001-12/2016
					A2	4/1953-9/1986; 8/2001-12/2016	
12	B2	Colorado Rv abv Silver, TX	08123850	9-1967-12/2016	B3	10/1958 - 12/2016	9-1967-12/2016
					B4	10/1947-9/1959 [1]	
					A1	6/1946-12/2016	
13	D4	Colorado Rv nr Ballinger, TX	08126380	1/1940-12/2016	B1	1/1940-4/1956; 10/1968-12/2016	1/1940-4/1956; 10/1968-12/2016
14	F1	Colorado Rv nr San Saba, TX	08147000	1/1940-12/2016	F2	10/1967-12/2016	10/1967-9/1993; 10/1997-12/2016
					D1	1/1940-9/1993; 10/1997-12/2016	
					E1	1/1940-9/1993; 10/1997-12/2016	

[1] Period of record deemed too limited, thus not considered in period described in column 8.

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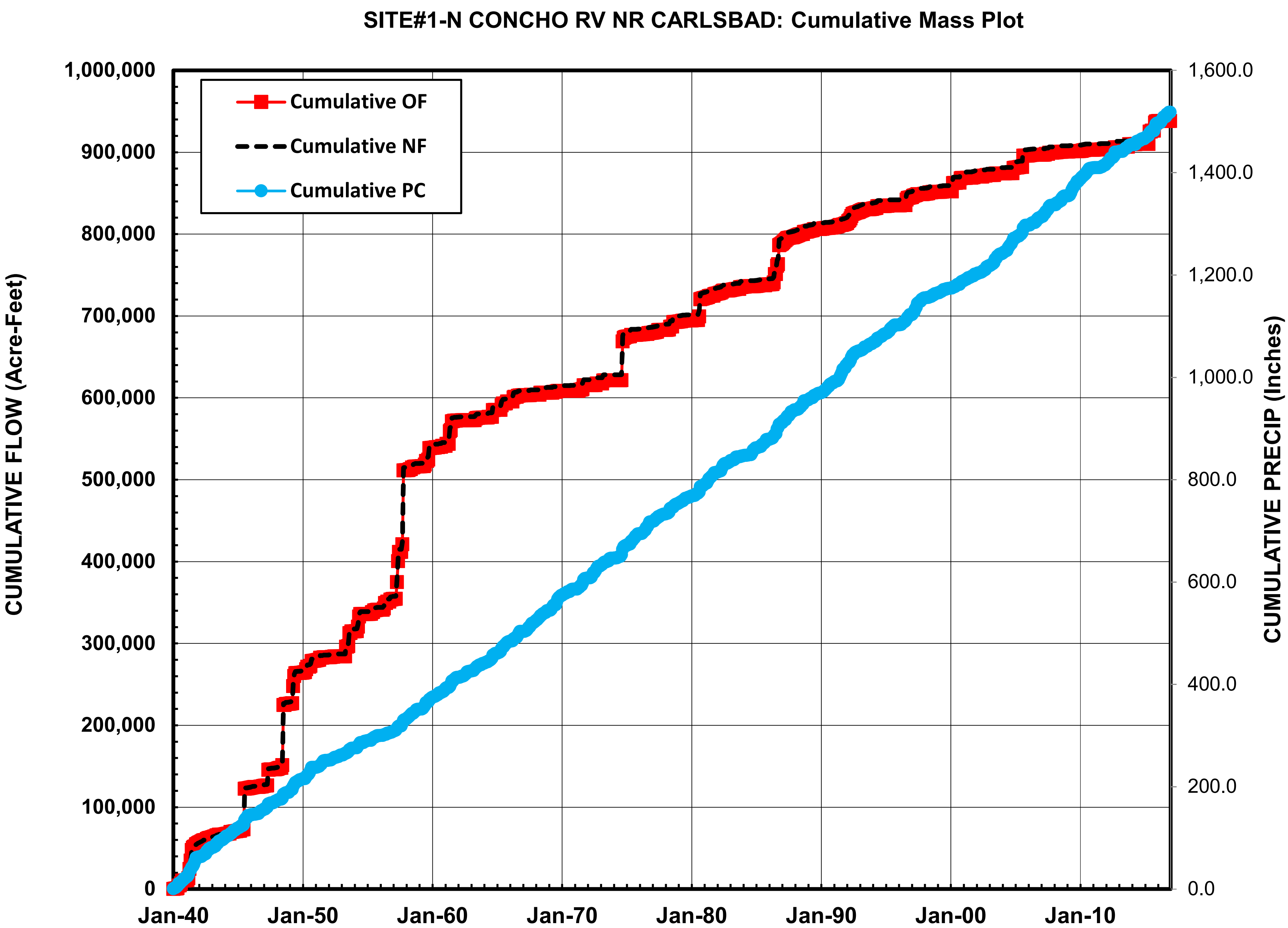
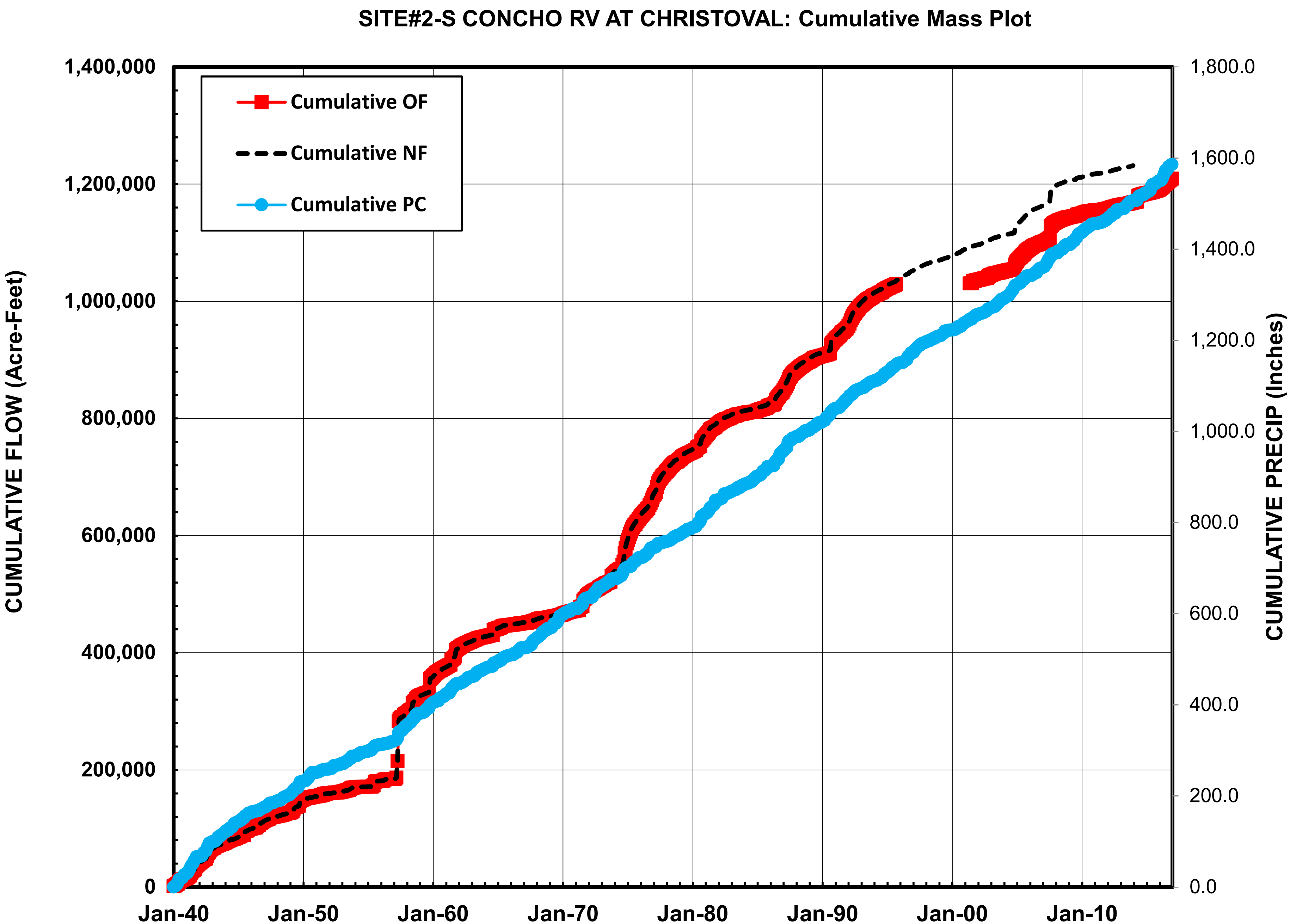
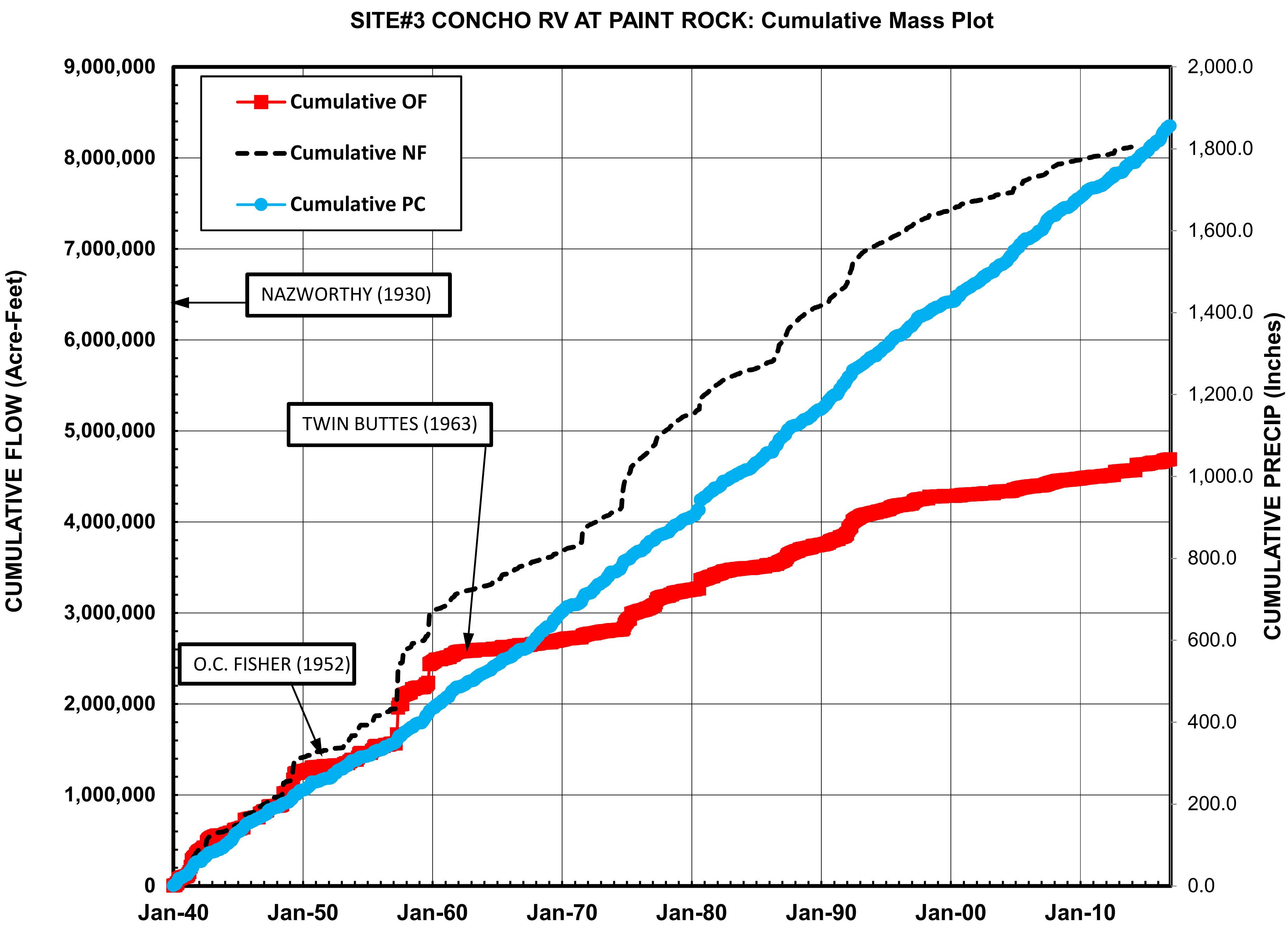
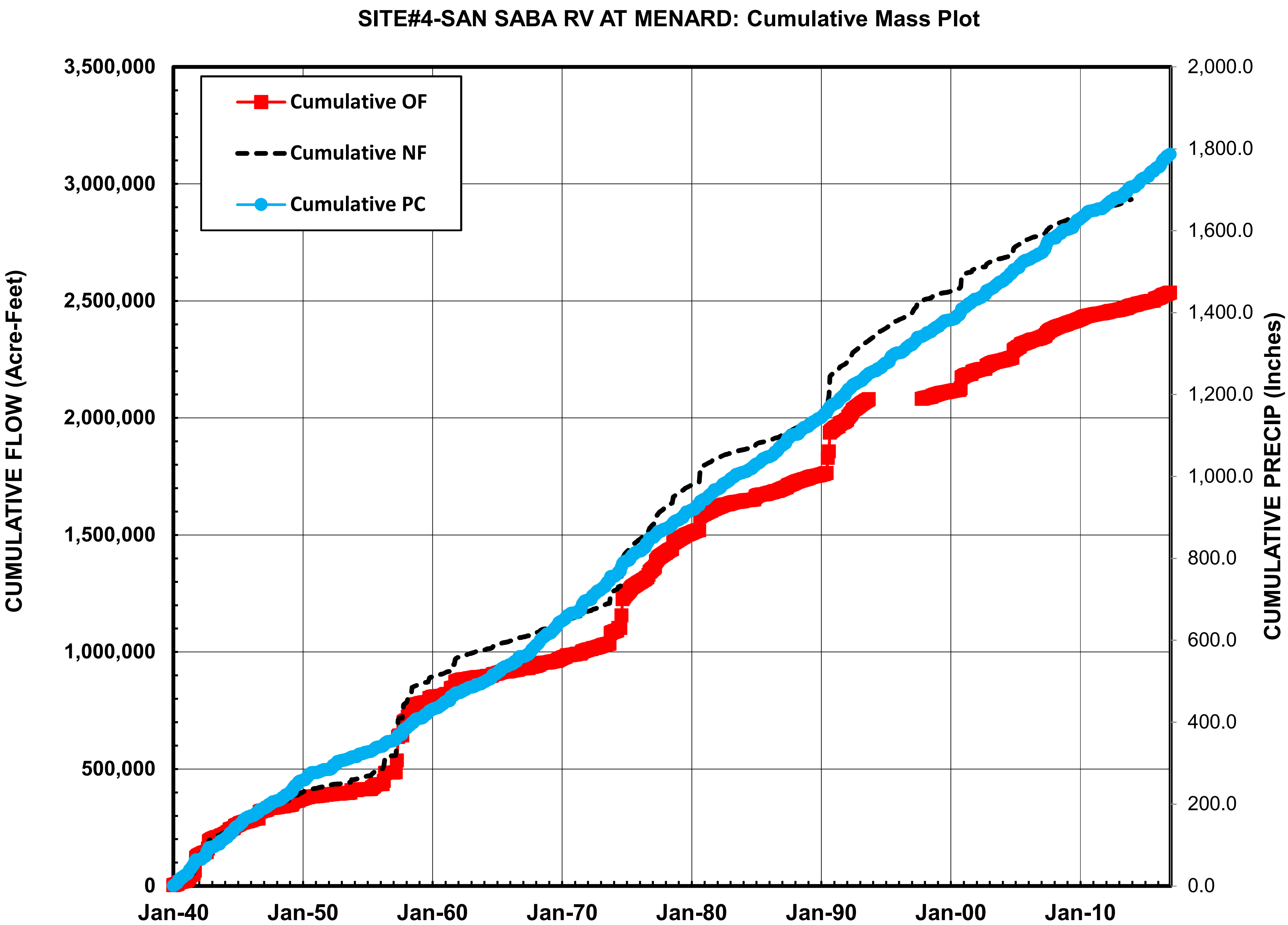
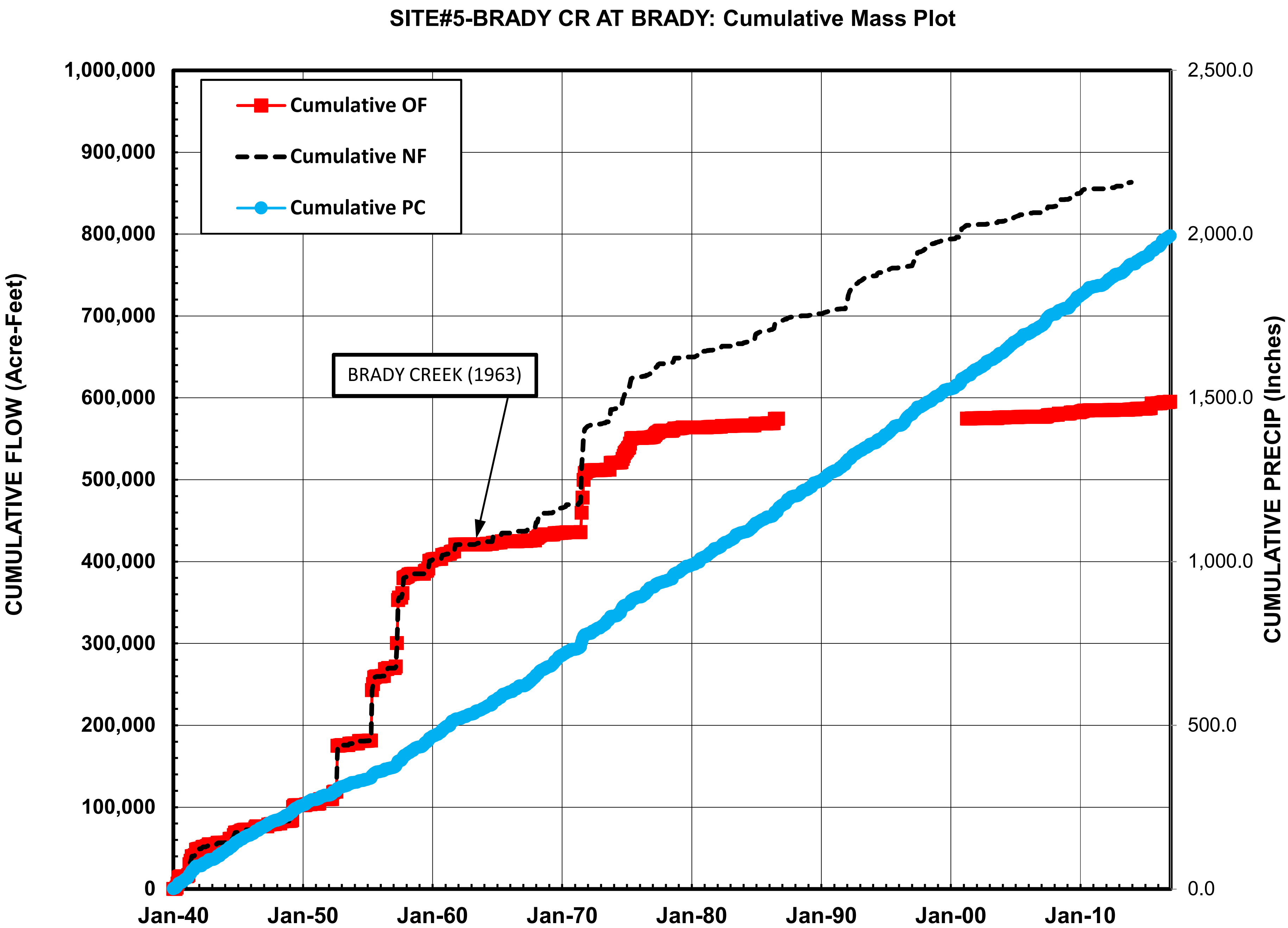
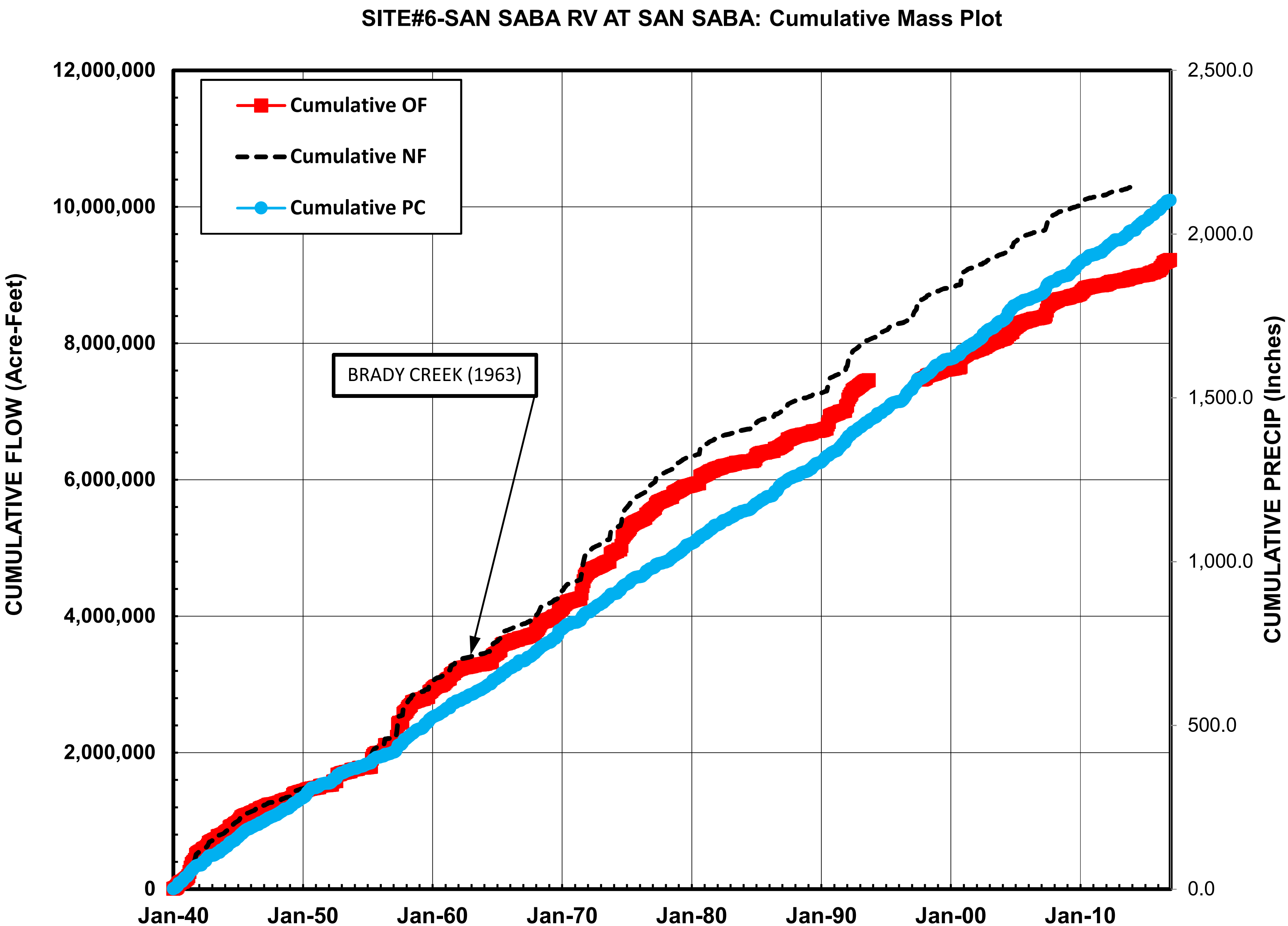

SITE#1-N CONCHO RV NR CARLSBAD: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

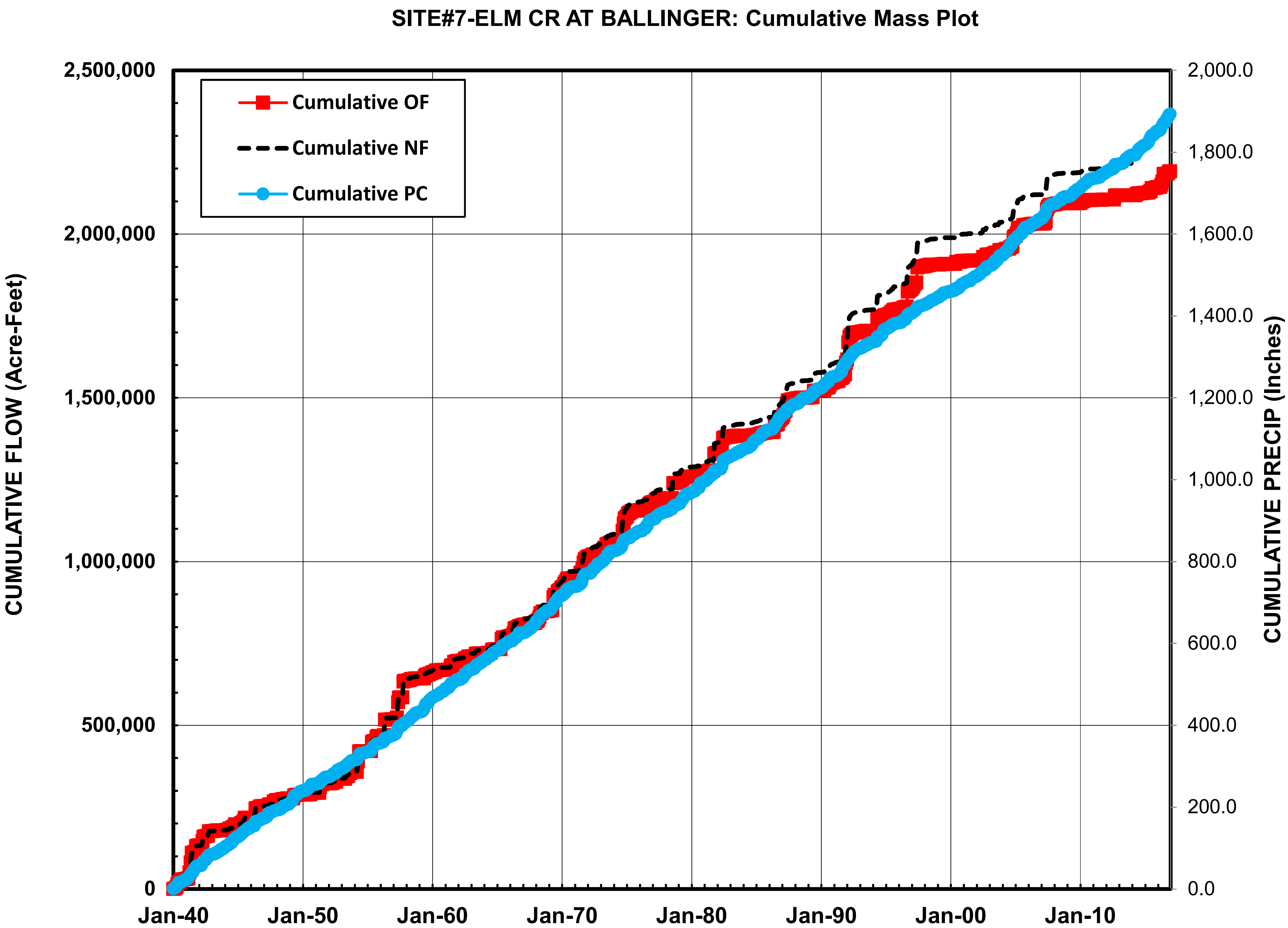

SITE#2-S CONCHO RV AT CHRISTOVAL: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
CUMULATIVE FLOW (Acre-Feet)
1,800.0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
CUMULATIVE PRECIP (Inches)
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

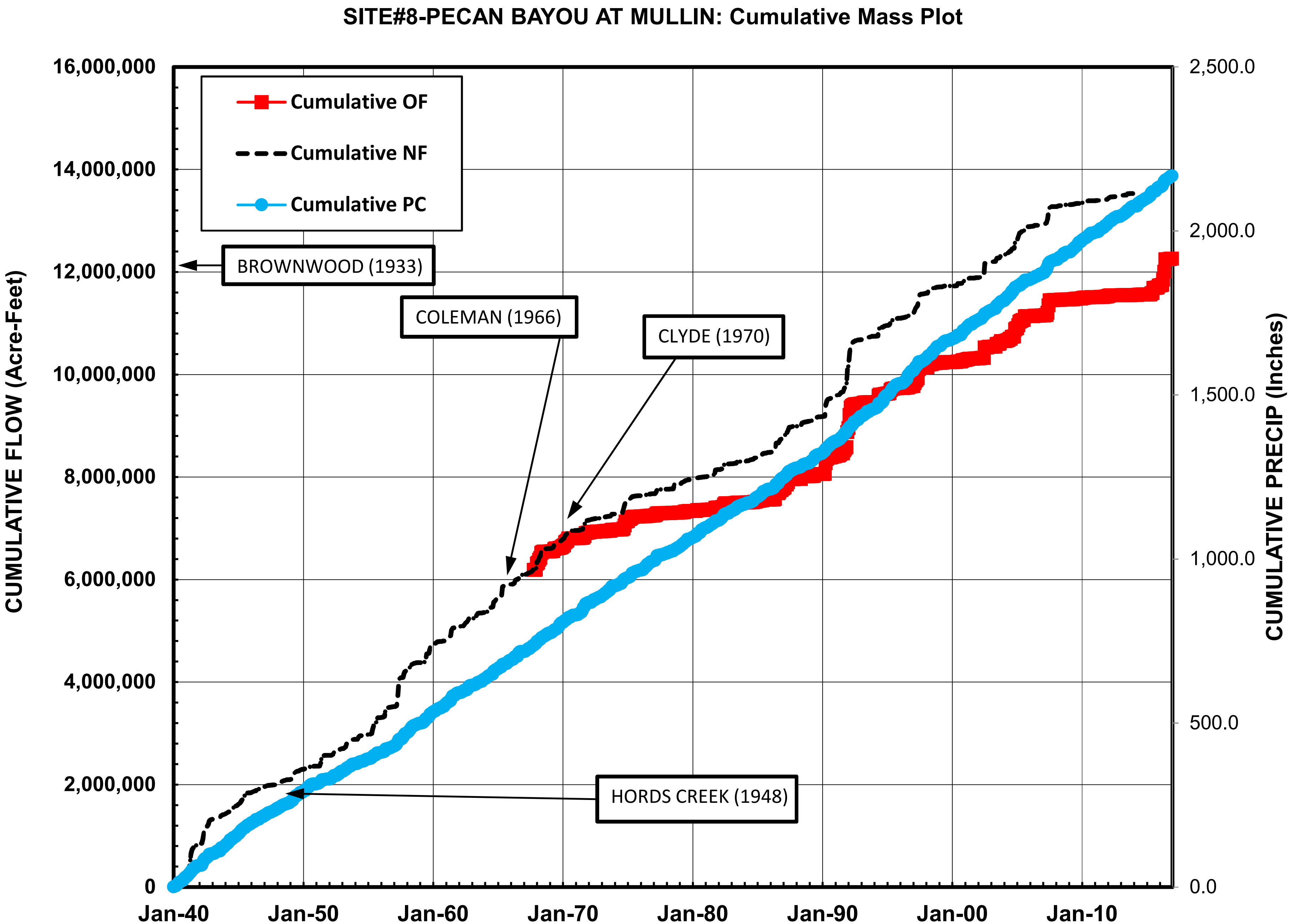

SITE#3 CONCHO RV AT PAINT ROCK: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
NAZWORTHY (1930)
TWIN BUTTES (1963)
O.C. FISHER (1952)
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
2,000.0
1,800.0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

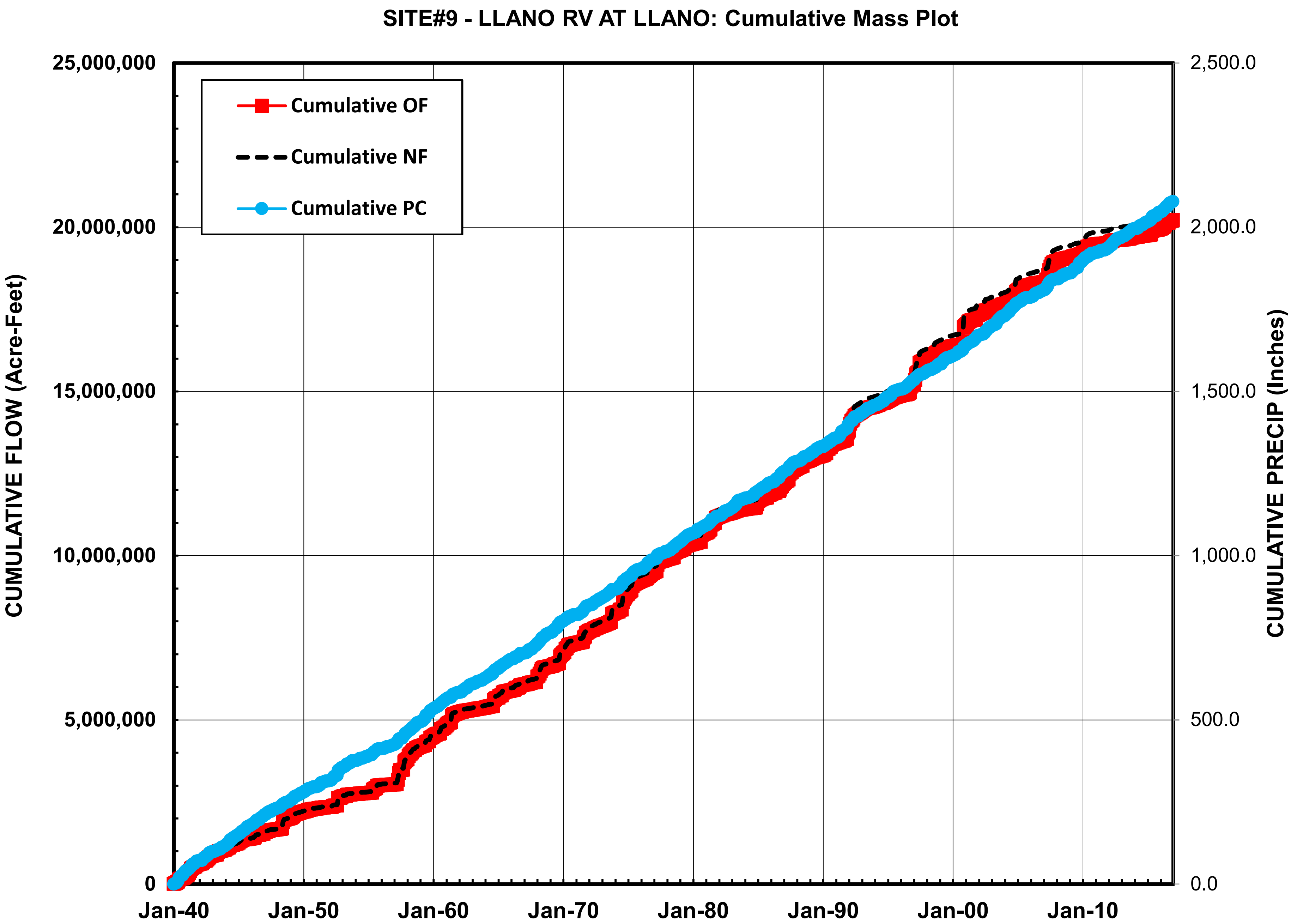

SITE#4-SAN SABA RV AT MENARD: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
2,000.0
1,800.0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

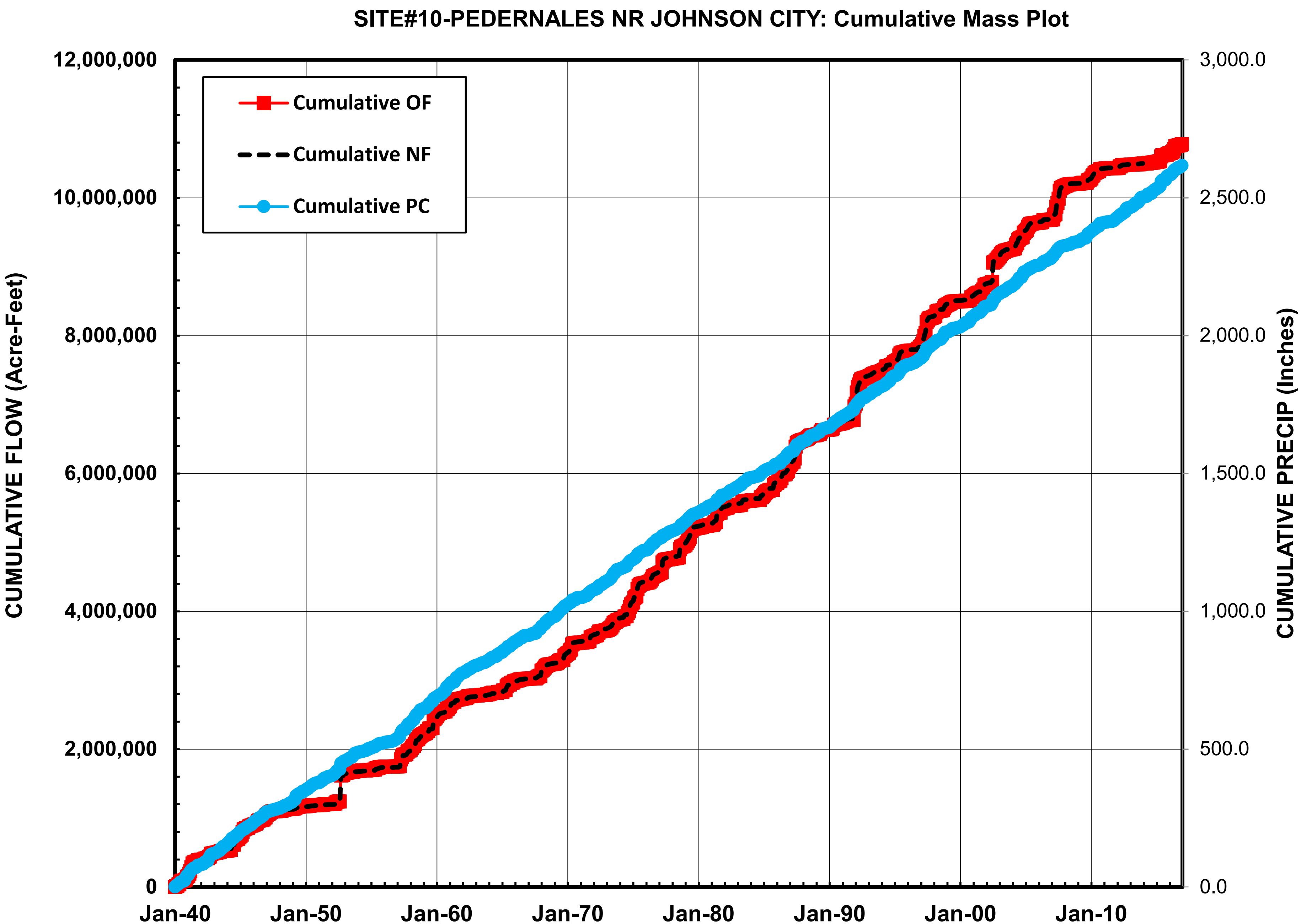

SITE#5-BRADY CR AT BRADY: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
BRADY CREEK (1963)
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

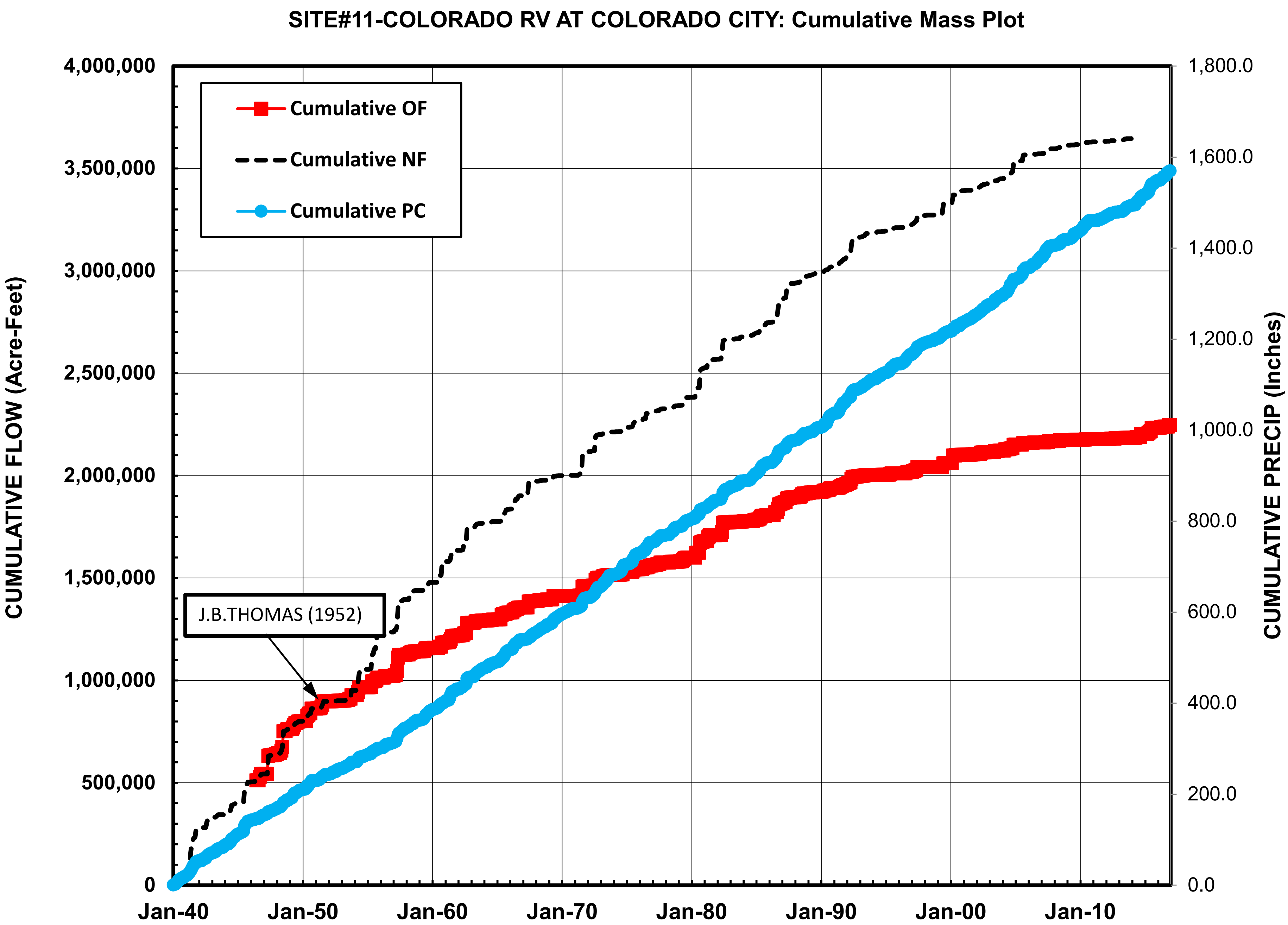

SITE#6-SAN SABA RV AT SAN SABA: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
BRADY CREEK (1963)
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

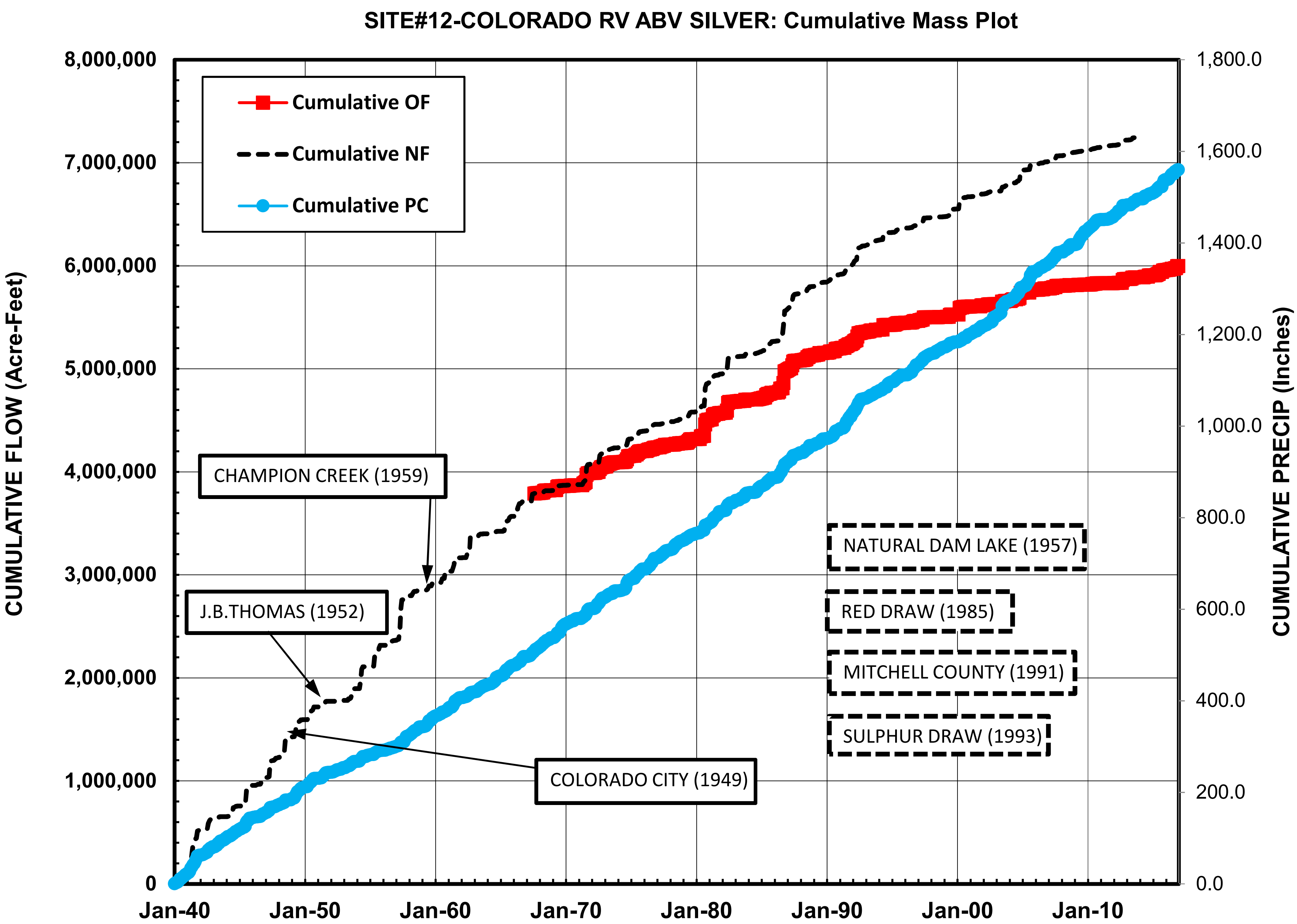

SITE#7-ELM CR AT BALLINGER: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
2,000.0
1,800.0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

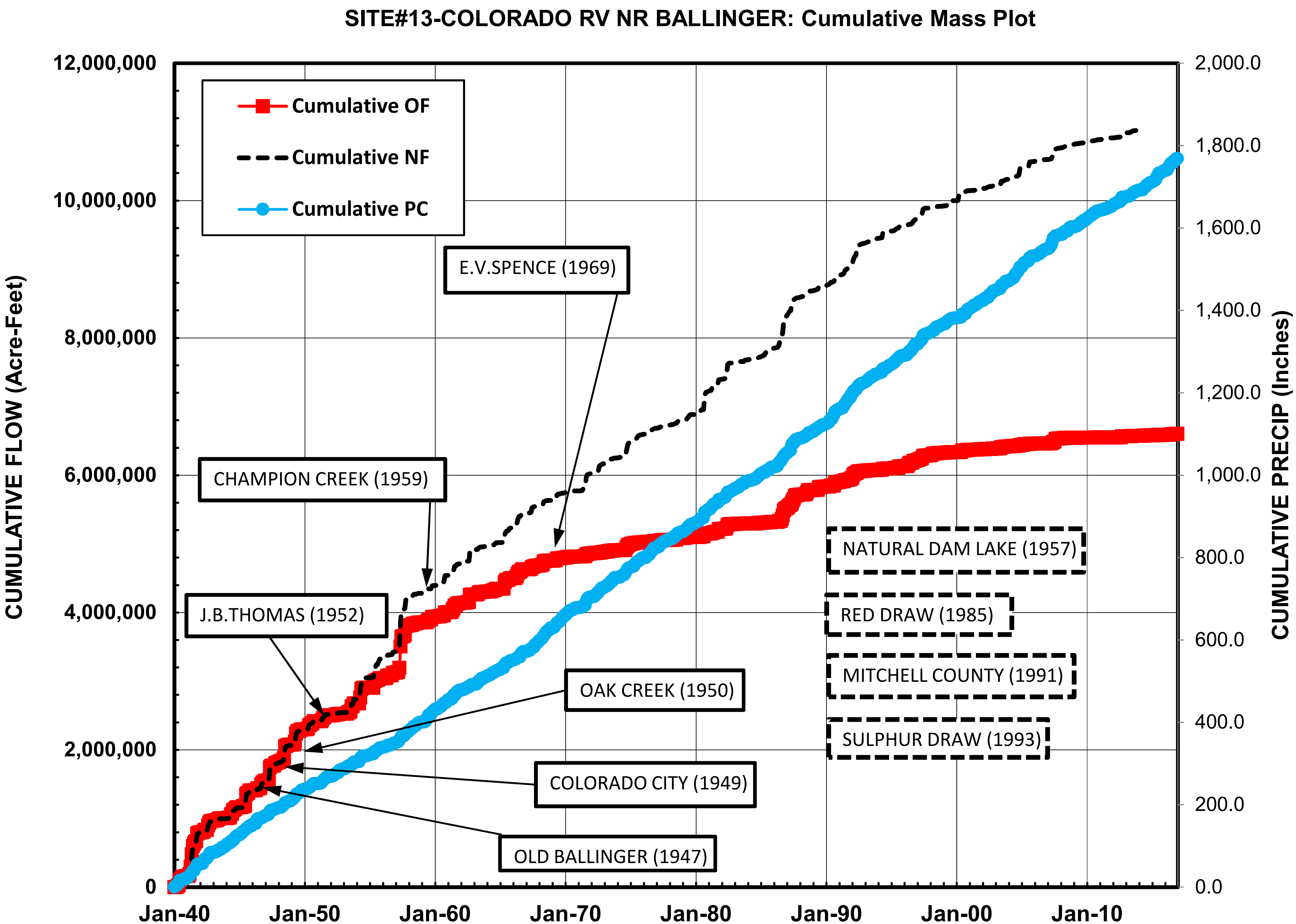

SITE#8-PECAN BAYOU AT MULLIN: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
BROWNWOOD (1933)
COLEMAN (1966)
CLYDE (1970)
HORDS CREEK (1948)
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

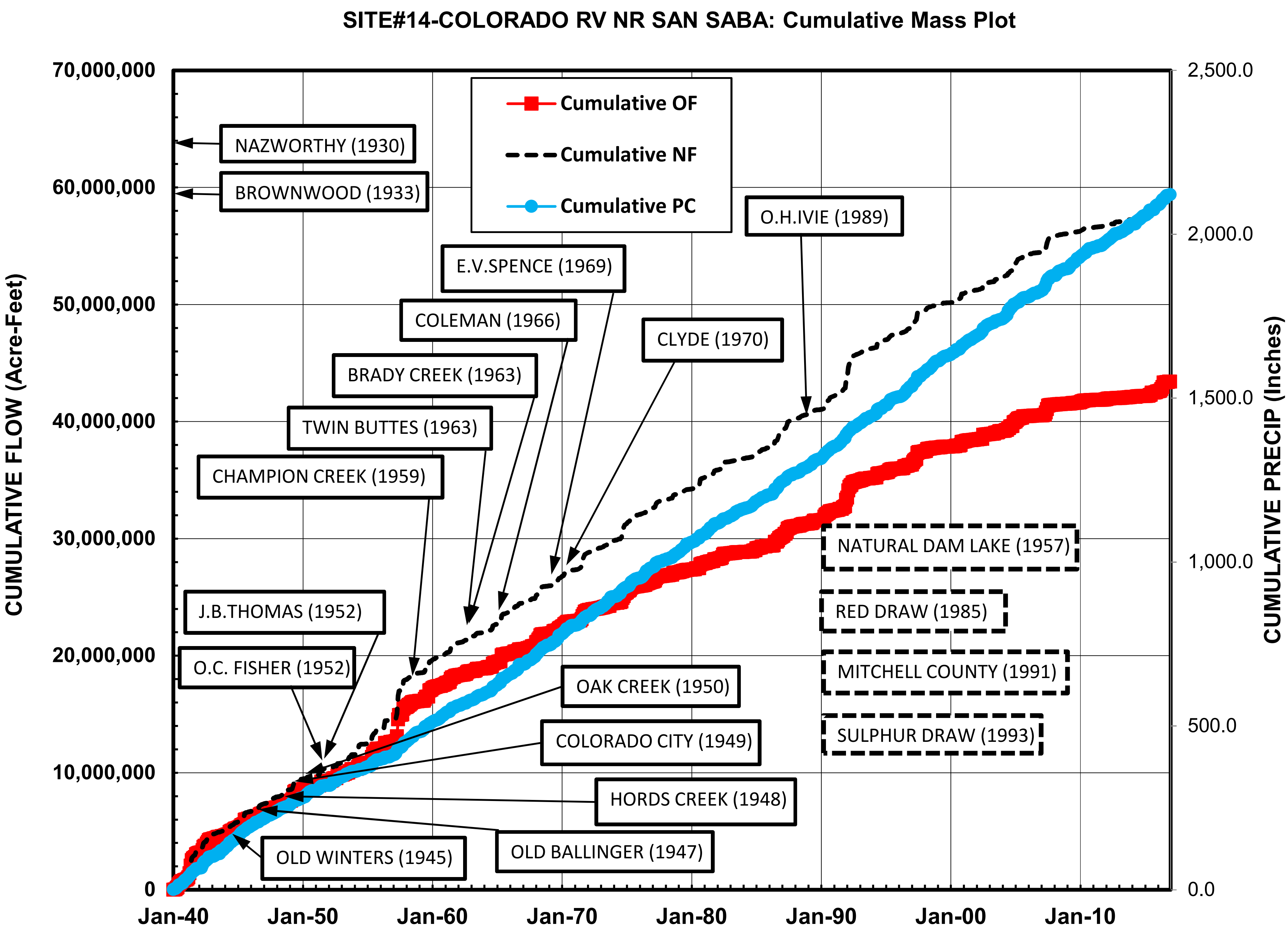

SITE#9 - LLANO RV AT LLANO: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

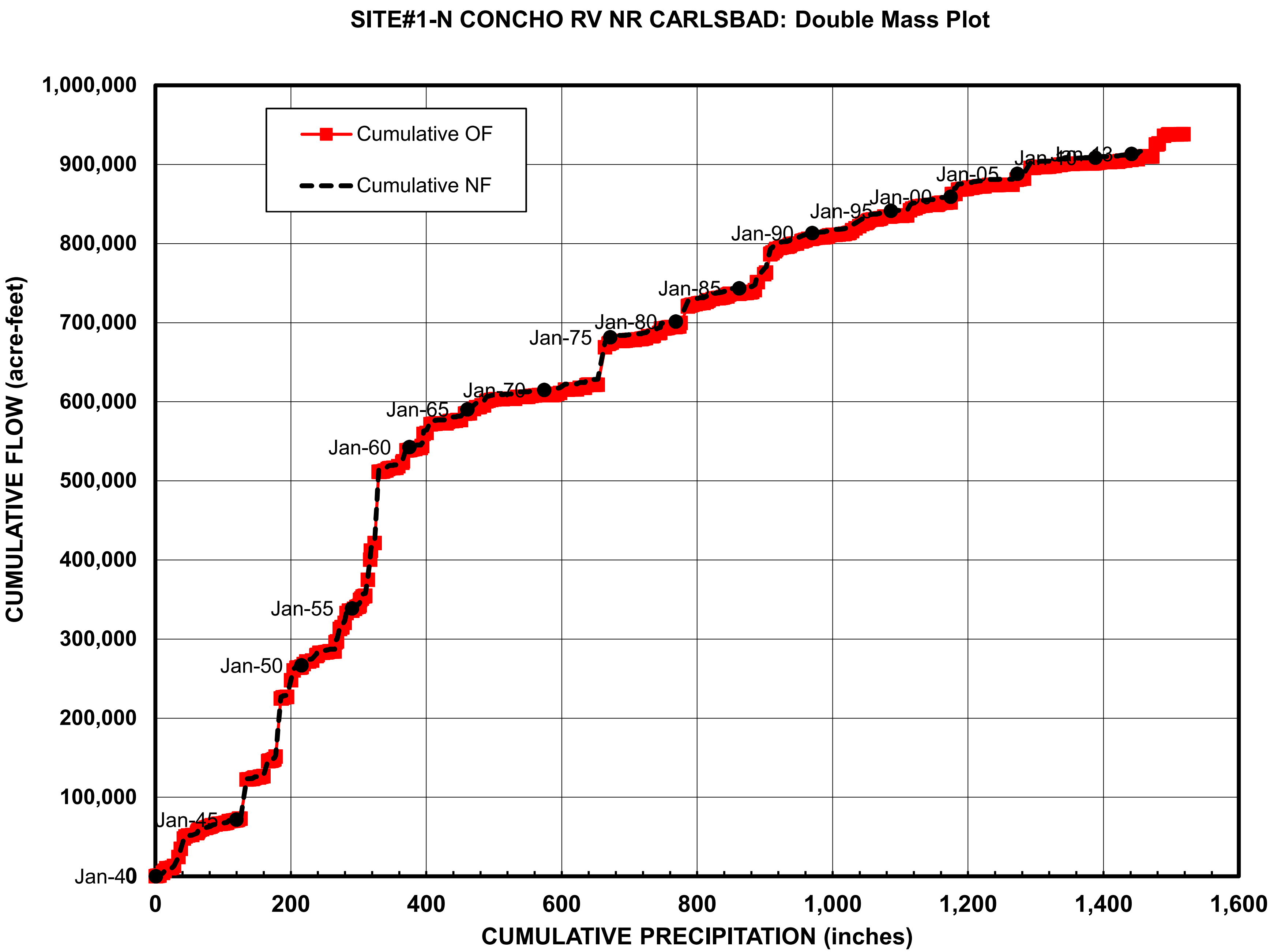

SITE#10-PEDERNALES NR JOHNSON CITY: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
3,000.0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

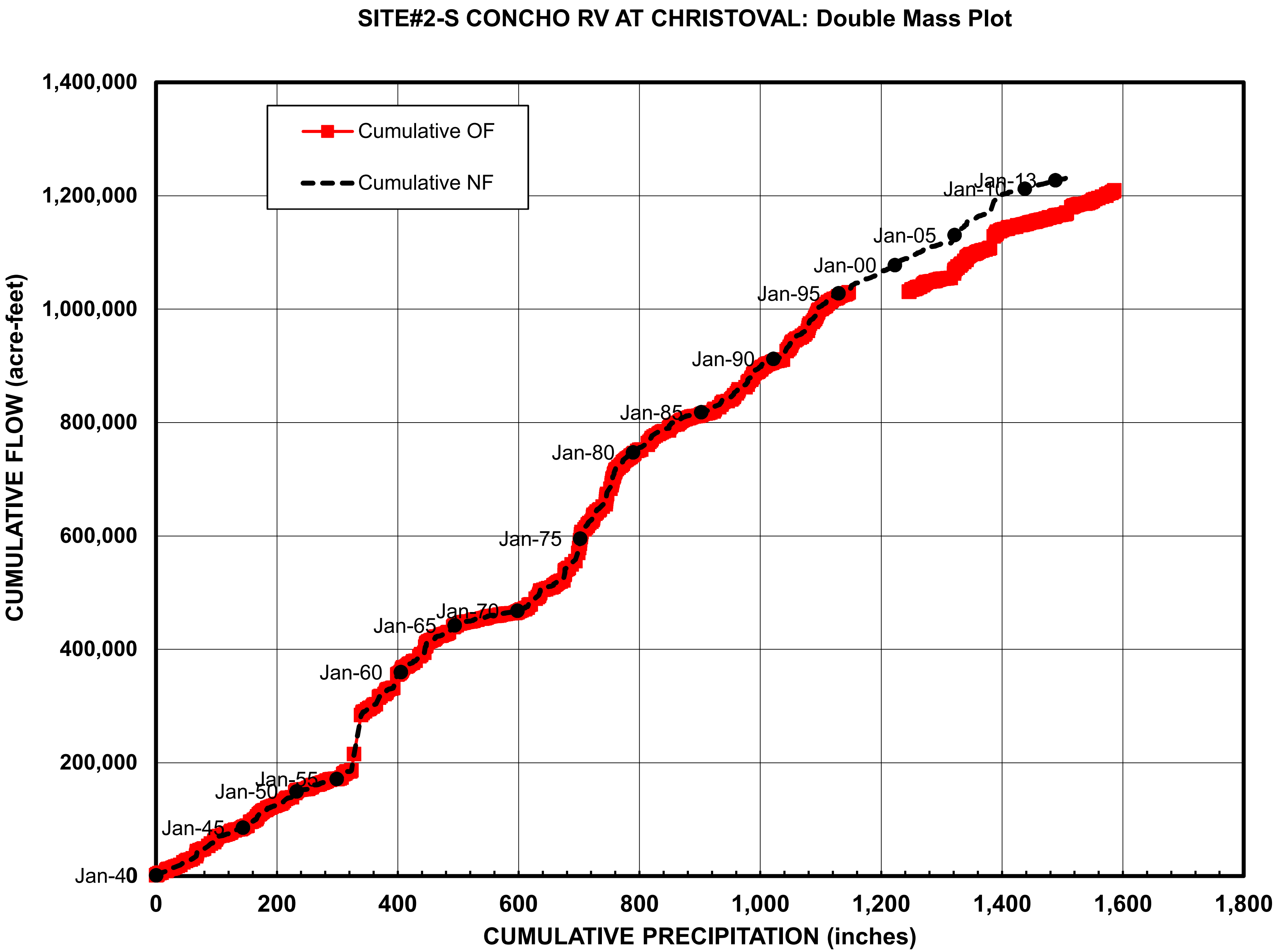

SITE#11-COLORADO RV AT COLORADO CITY: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
J.B.THOMAS (1952)
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1,800.0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


SITE#12-COLORADO RV ABV SILVER: Cumulative Mass Plot
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1,800.0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10
Cumulative OF
Cumulative NF
Cumulative PC
CHAMPION CREEK (1959)
J.B.THOMAS (1952)
COLORADO CITY (1949)
NATURAL DAM LAKE (1957)
RED DRAW (1985)
MITCHELL COUNTY (1991)
SULPHUR DRAW (1993)

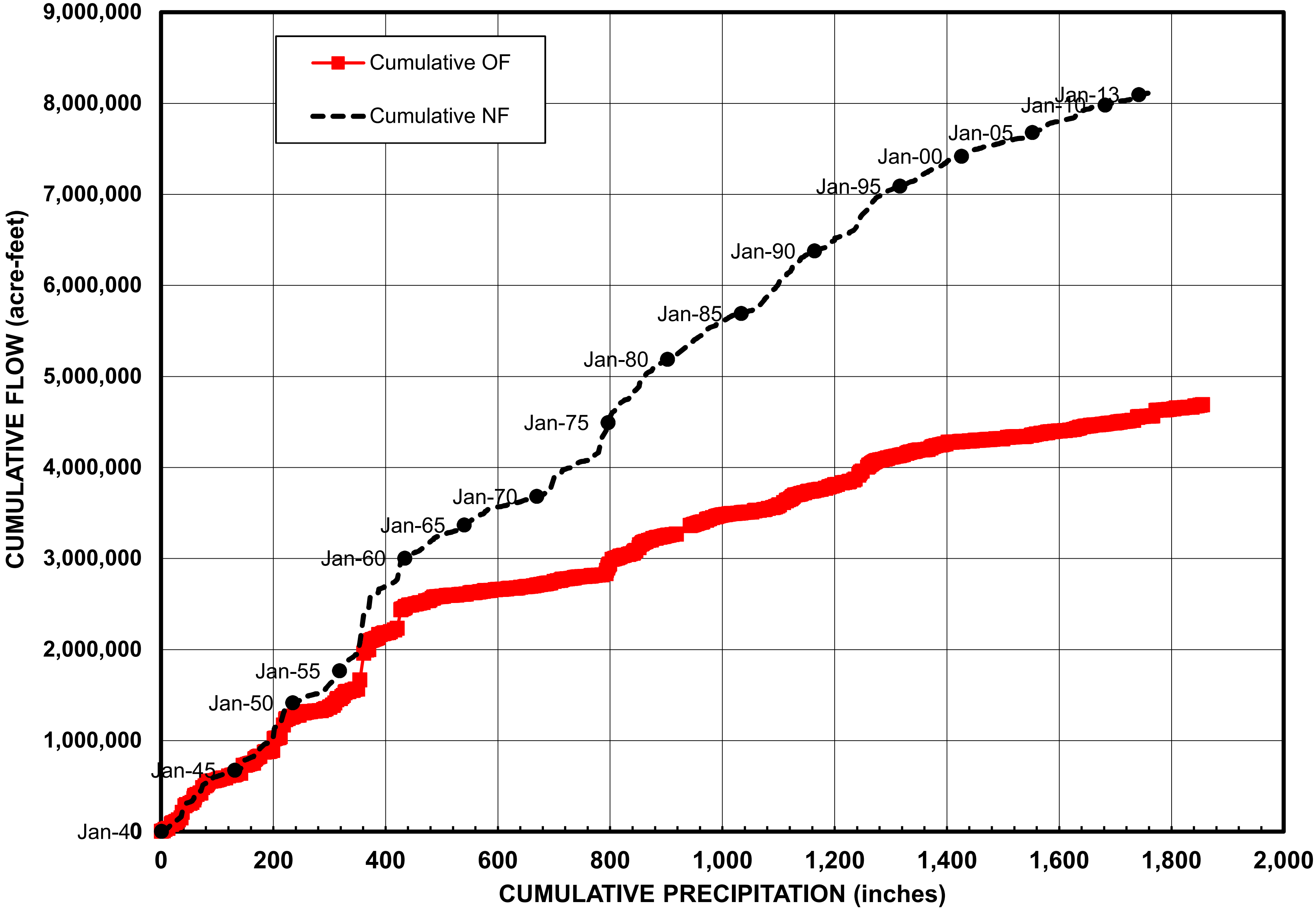

SITE#13-COLORADO RV NR BALLINGER: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
E.V.SPENCE (1969)
CHAMPION CREEK (1959)
J.B.THOMAS (1952)
OAK CREEK (1950)
COLORADO CITY (1949)
OLD BALLINGER (1947)
NATURAL DAM LAKE (1957)
RED DRAW (1985)
MITCHELL COUNTY (1991)
SULPHUR DRAW (1993)
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
0.0
200.0
400.0
600.0
800.0
1,000.0
1,200.0
1,400.0
1,600.0
1,800.0
2,000.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

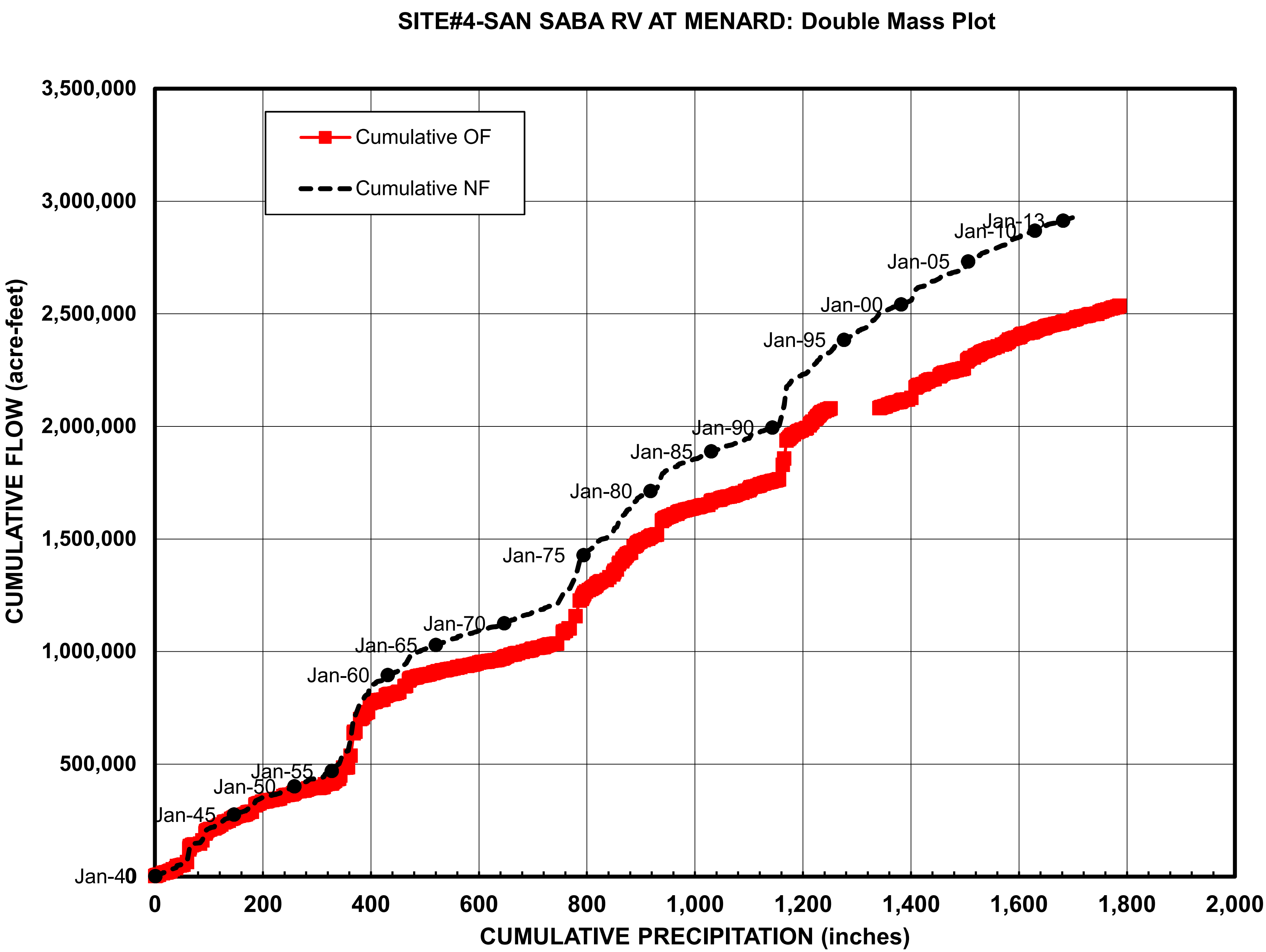

SITE#14-COLORADO RV NR SAN SABA: Cumulative Mass Plot
Cumulative OF
Cumulative NF
Cumulative PC
CUMULATIVE FLOW (Acre-Feet)
CUMULATIVE PRECIP (Inches)
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10
NAZWORTHY (1930)
BROWNWOOD (1933)
O.H.IVIE (1989)
E.V.SPENCE (1969)
COLEMAN (1966)
CLYDE (1970)
BRADY CREEK (1963)
TWIN BUTTES (1963)
CHAMPION CREEK (1959)
NATURAL DAM LAKE (1957)
RED DRAW (1985)
MITCHELL COUNTY (1991)
SULPHUR DRAW (1993)
J.B.THOMAS (1952)
O.C. FISHER (1952)
OAK CREEK (1950)
COLORADO CITY (1949)
HORDS CREEK (1948)
OLD BALLINGER (1947)
OLD WINTERS (1945)

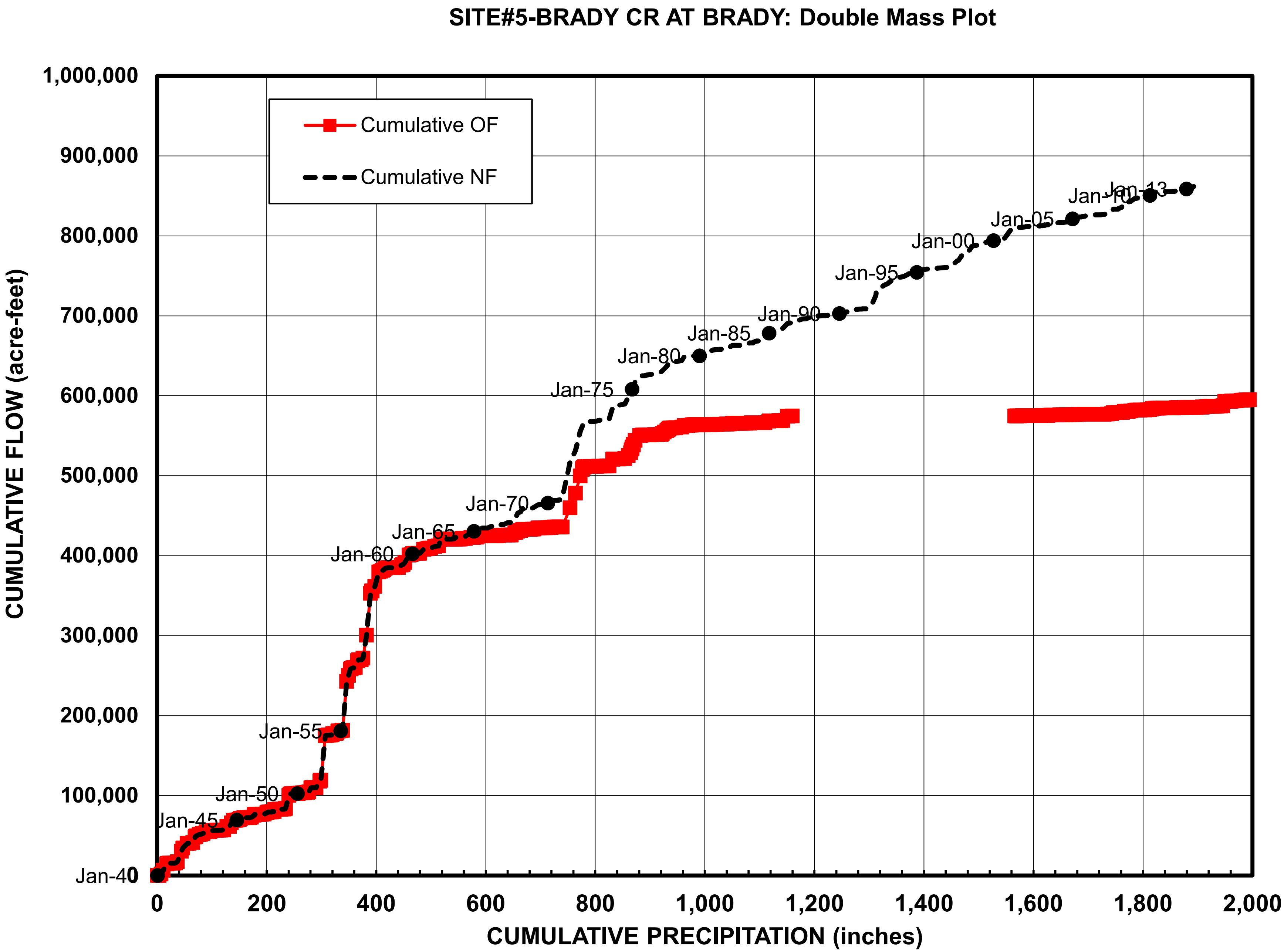

SITE#1-N CONCHO RV NR CARLSBAD: Double Mass Plot
Cumulative OF
Cumulative NF
CUMULATIVE FLOW (acre-feet)
CUMULATIVE PRECIPITATION (inches)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0
200
400
600
800
1,000
1,200
1,400
1,600
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13


SITE#2-S CONCHO RV AT CHRISTOVAL: Double Mass Plot
Cumulative OF
Cumulative NF
CUMULATIVE FLOW (acre-feet)
CUMULATIVE PRECIPITATION (inches)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13

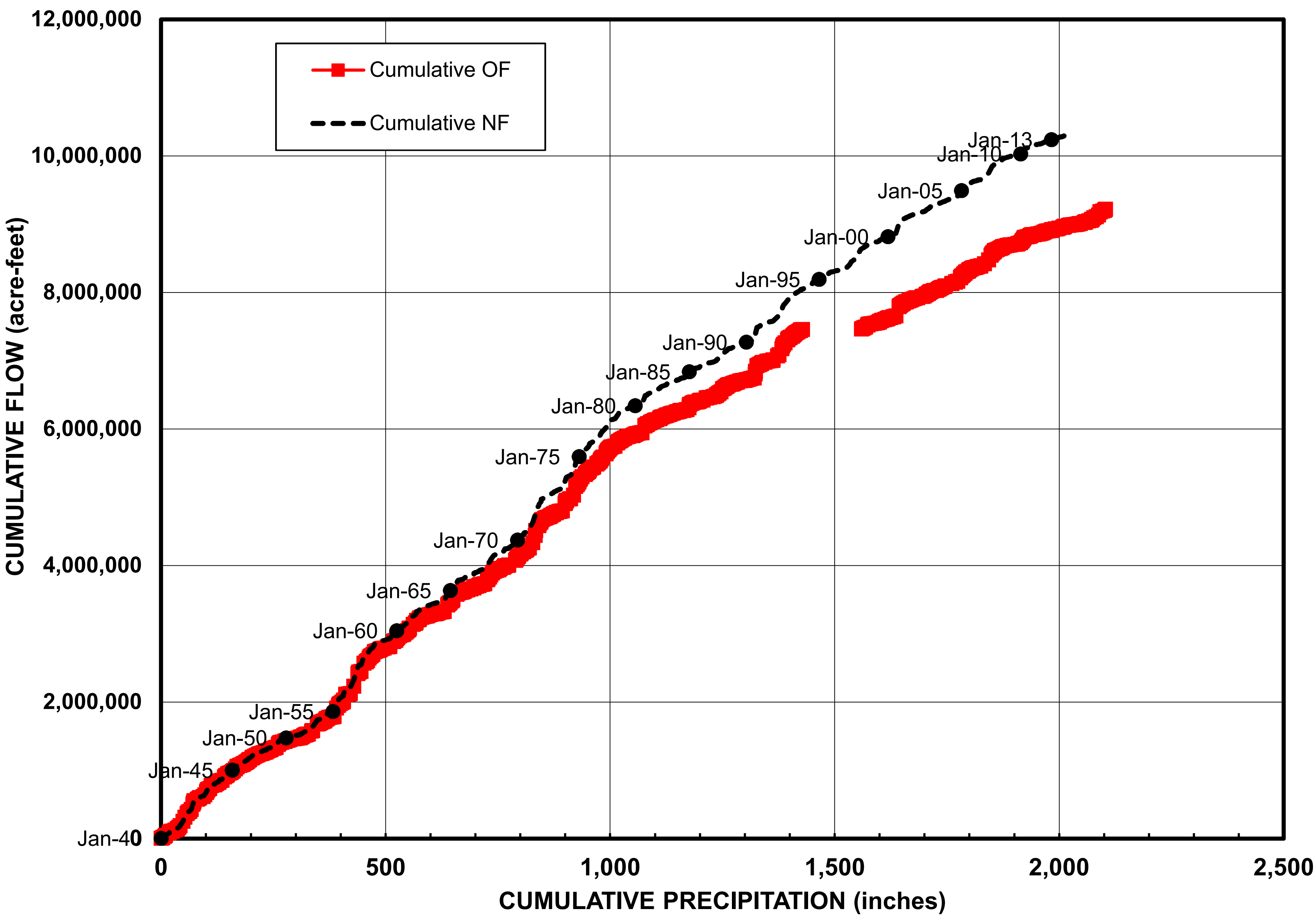
SITE#3 CONCHO RV AT PAINT ROCK: Double Mass Plot



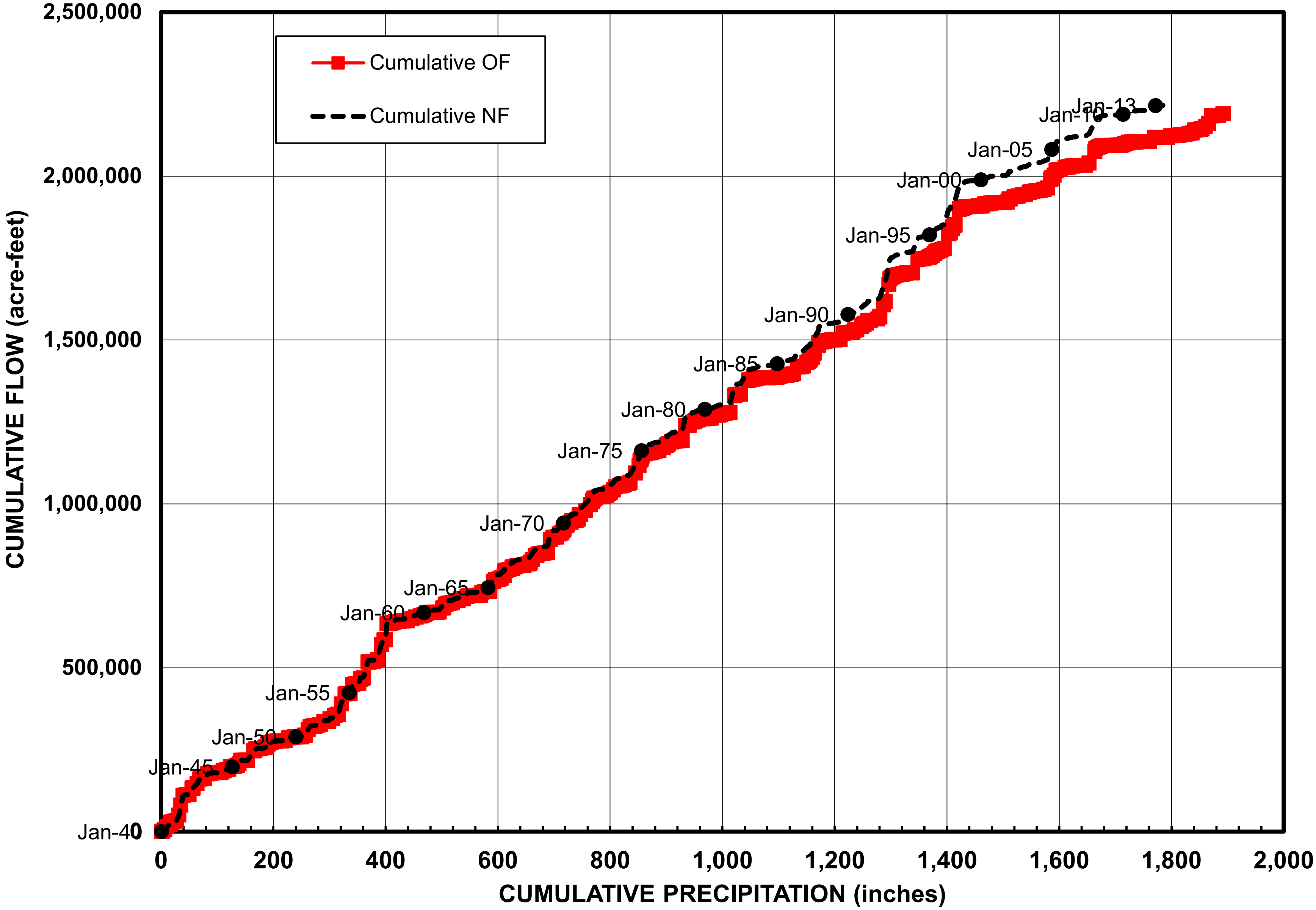

SITE#4-SAN SABA RV AT MENARD: Double Mass Plot
Cumulative OF
Cumulative NF
CUMULATIVE FLOW (acre-feet)
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
CUMULATIVE PRECIPITATION (inches)
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13

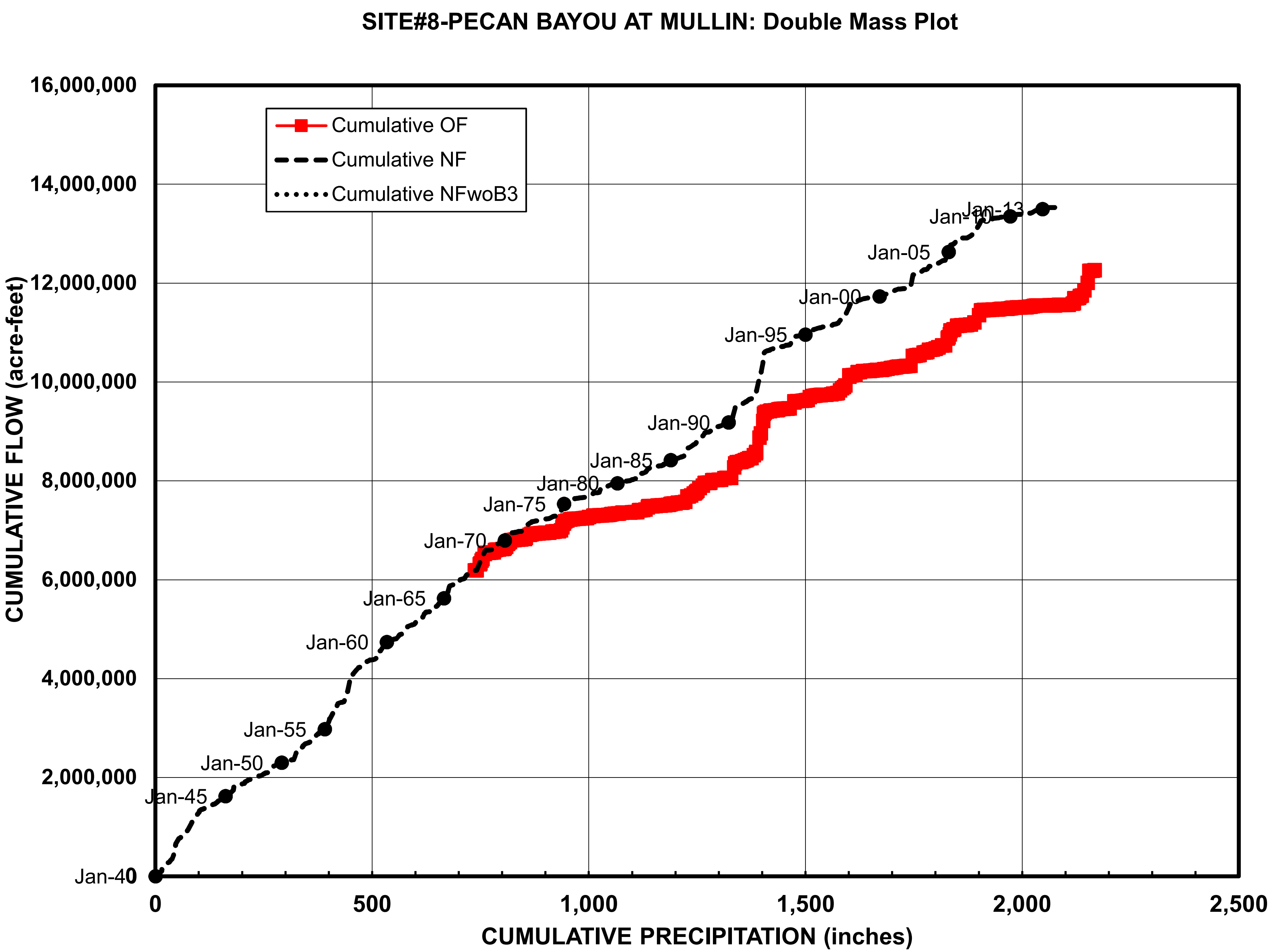

SITE#5-BRADY CR AT BRADY: Double Mass Plot
CUMULATIVE FLOW (acre-feet)
CUMULATIVE PRECIPITATION (inches)
Cumulative OF
Cumulative NF
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13

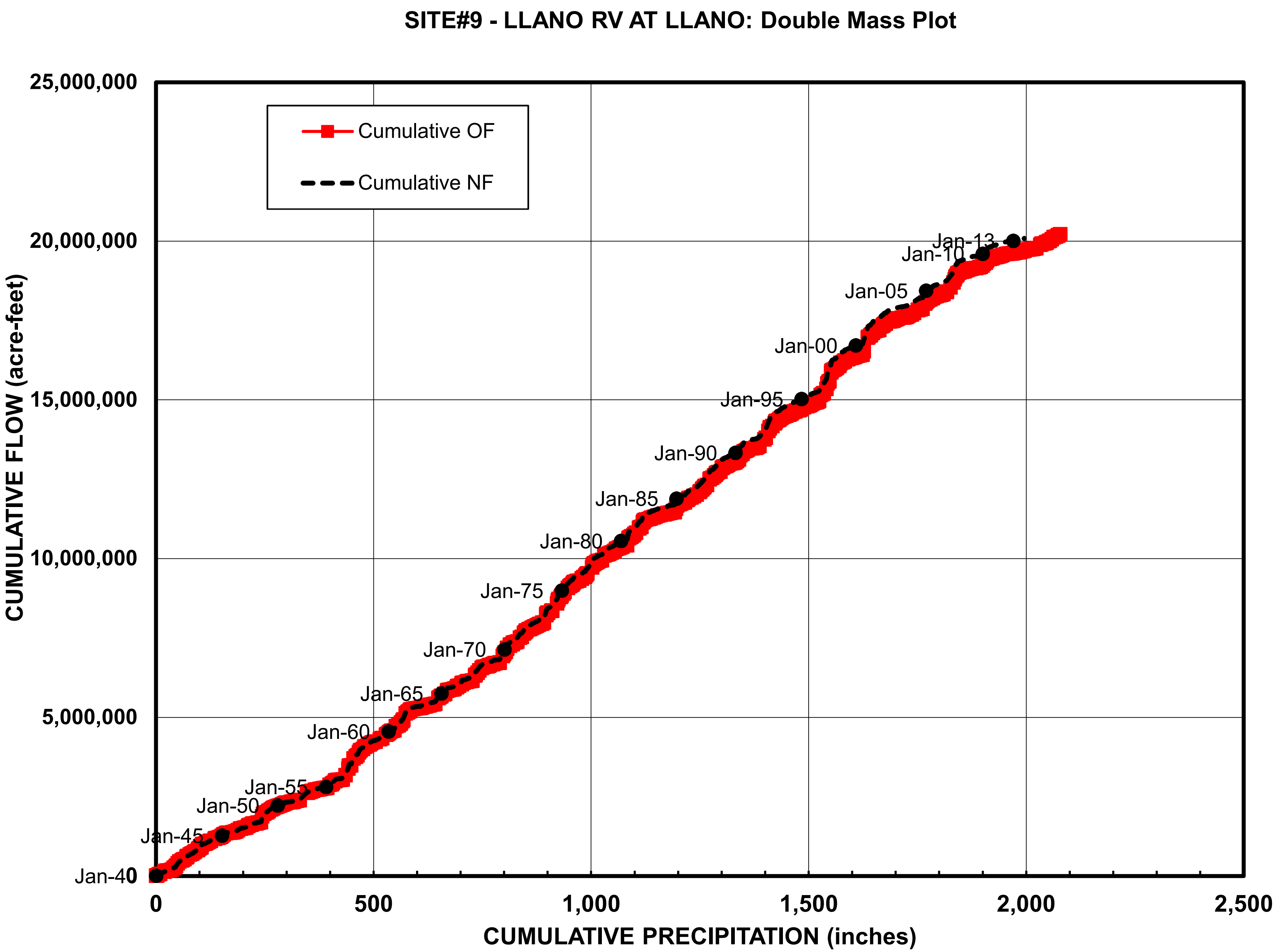
SITE#6-SAN SABA RV AT SAN SABA: Double Mass Plot



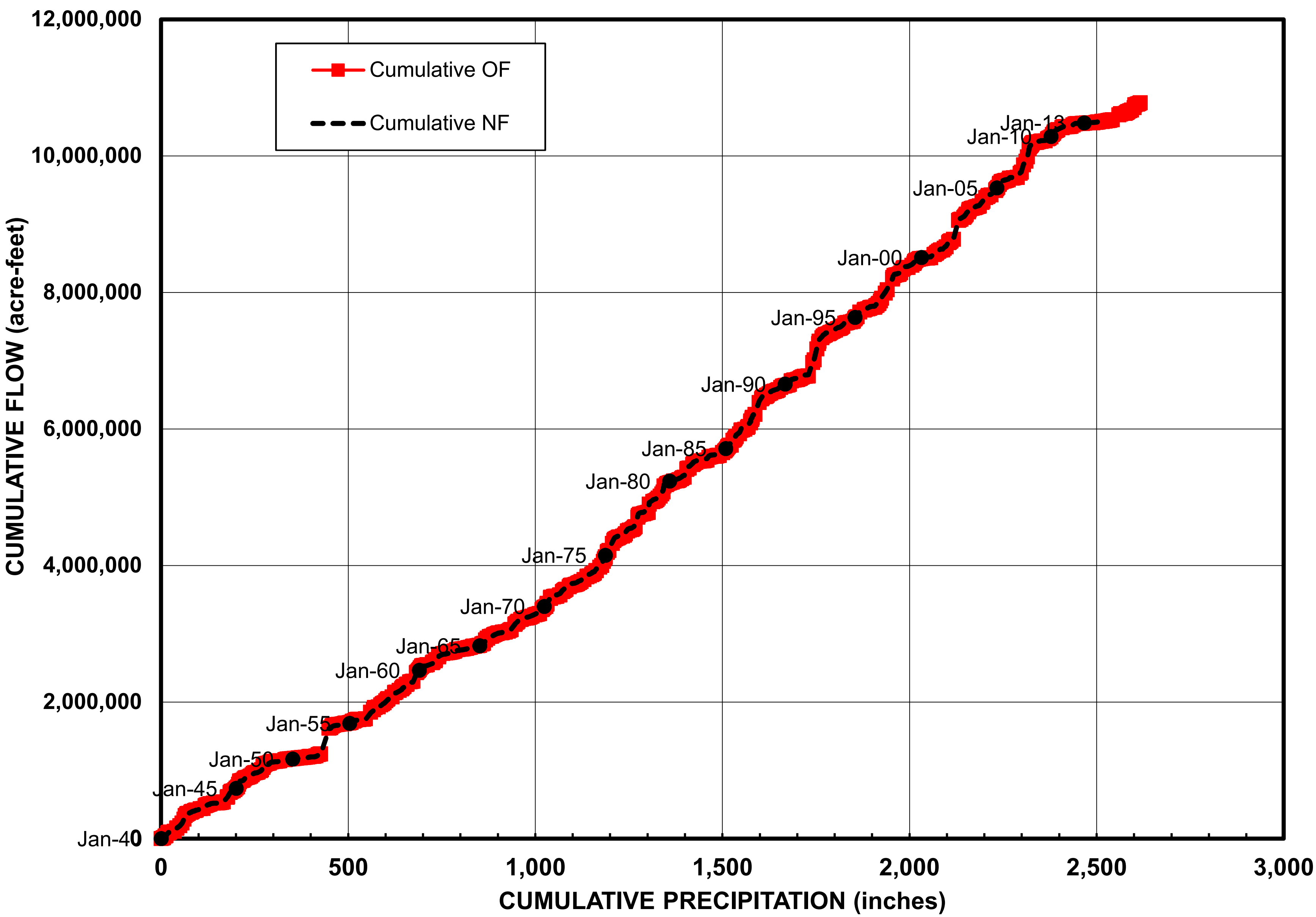
SITE#7-ELM CR AT BALLINGER: Double Mass Plot

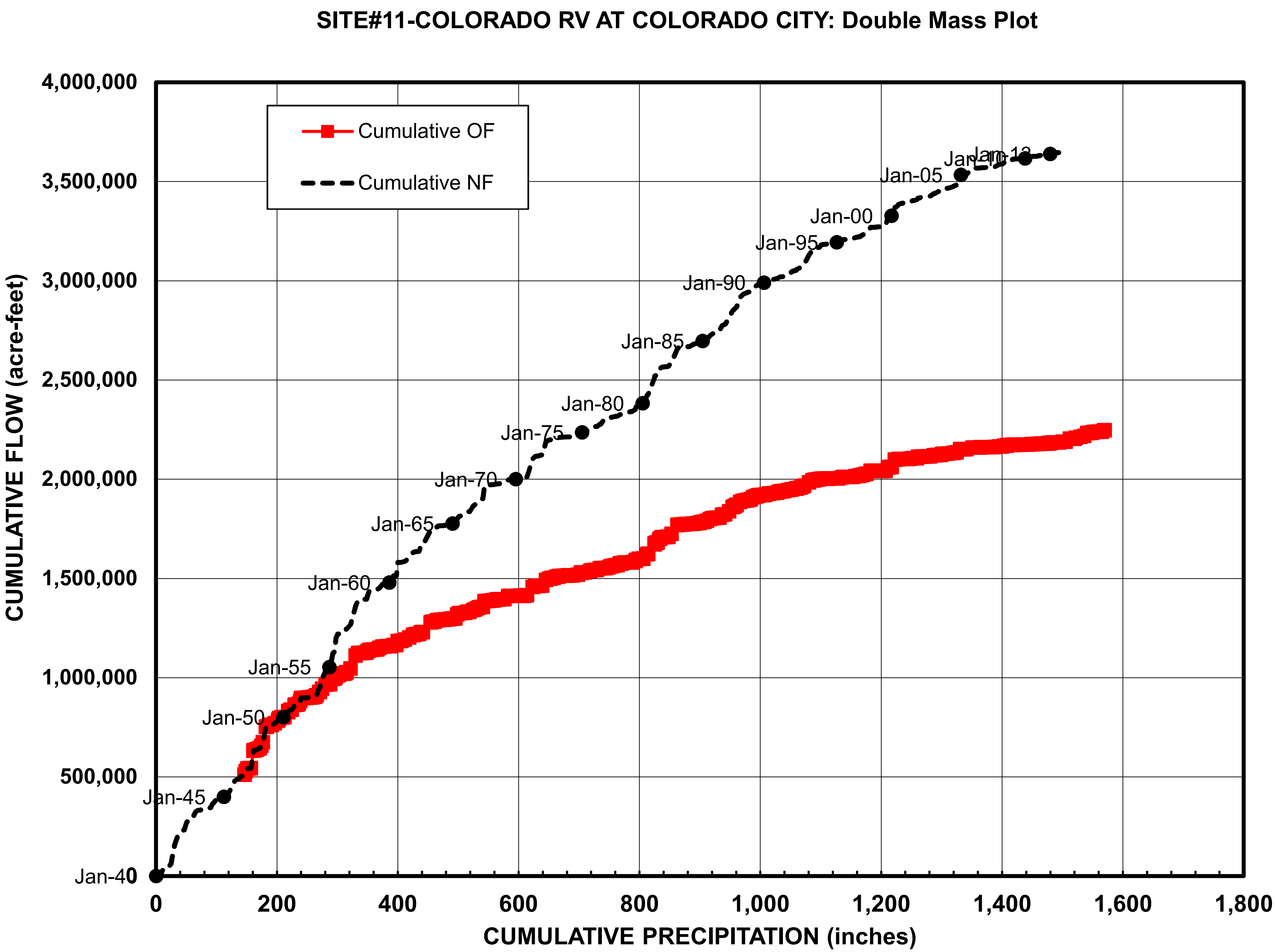



SITE#8-PECAN BAYOU AT MULLIN: Double Mass Plot
Cumulative OF
Cumulative NF
Cumulative NFwoB3
CUMULATIVE FLOW (acre-feet)
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13
0
500
1,000
1,500
2,000
2,500
CUMULATIVE PRECIPITATION (inches)

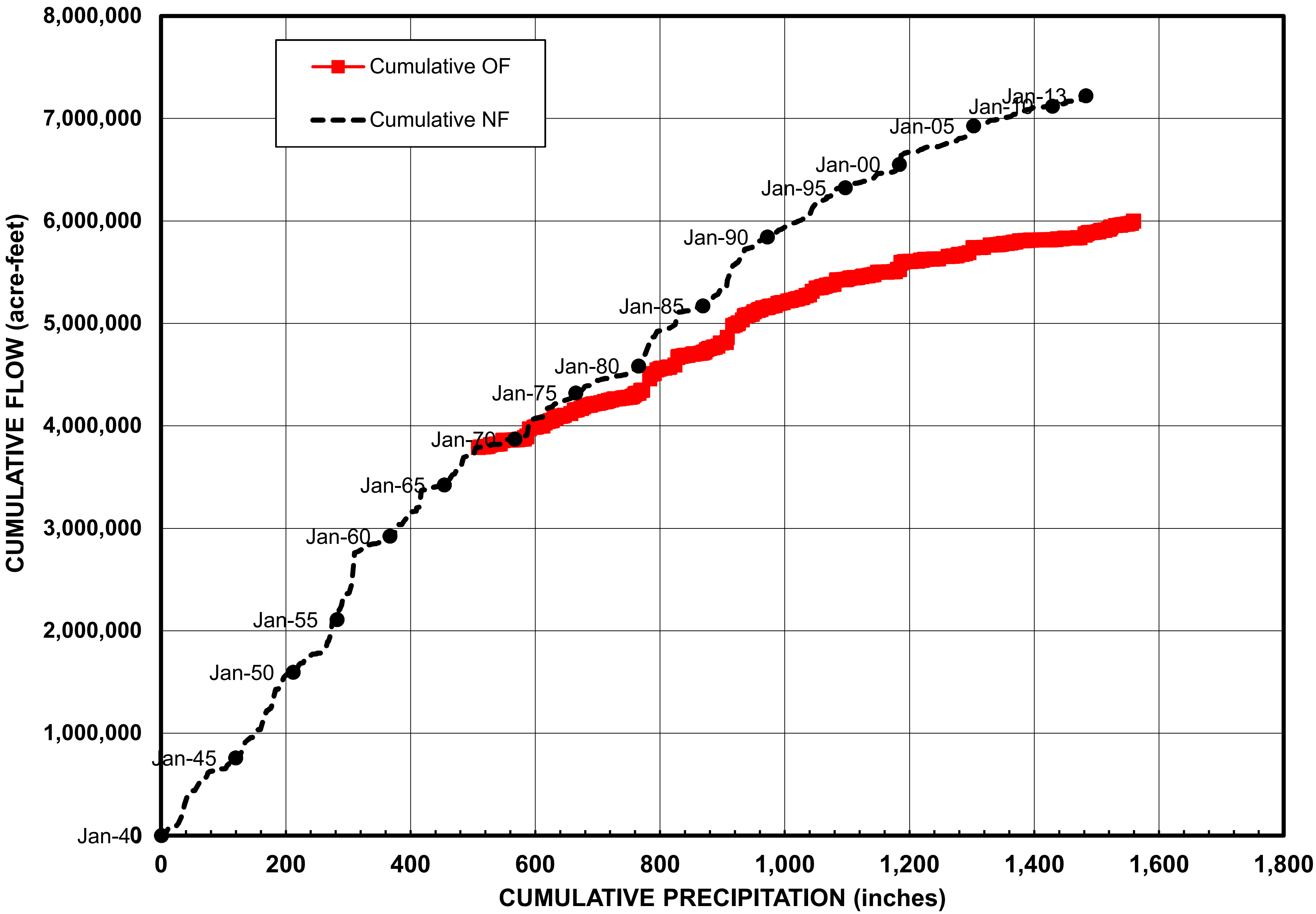

SITE#9 - LLANO RV AT LLANO: Double Mass Plot
Cumulative OF
Cumulative NF
CUMULATIVE FLOW (acre-feet)
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
CUMULATIVE PRECIPITATION (inches)
0
500
1,000
1,500
2,000
2,500
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13

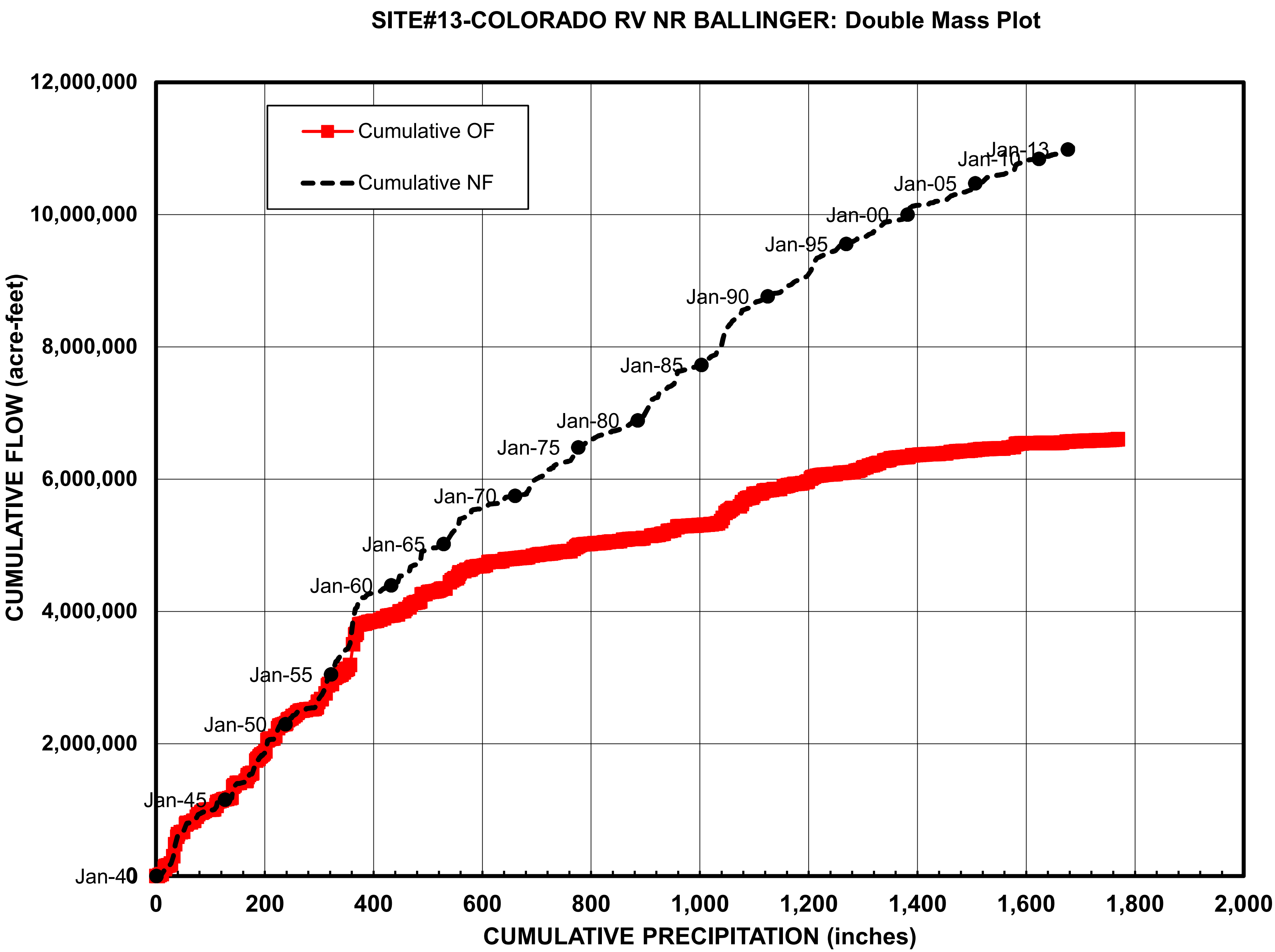
SITE#10-PEDERNALES NR JOHNSON CITY: Double Mass Plot

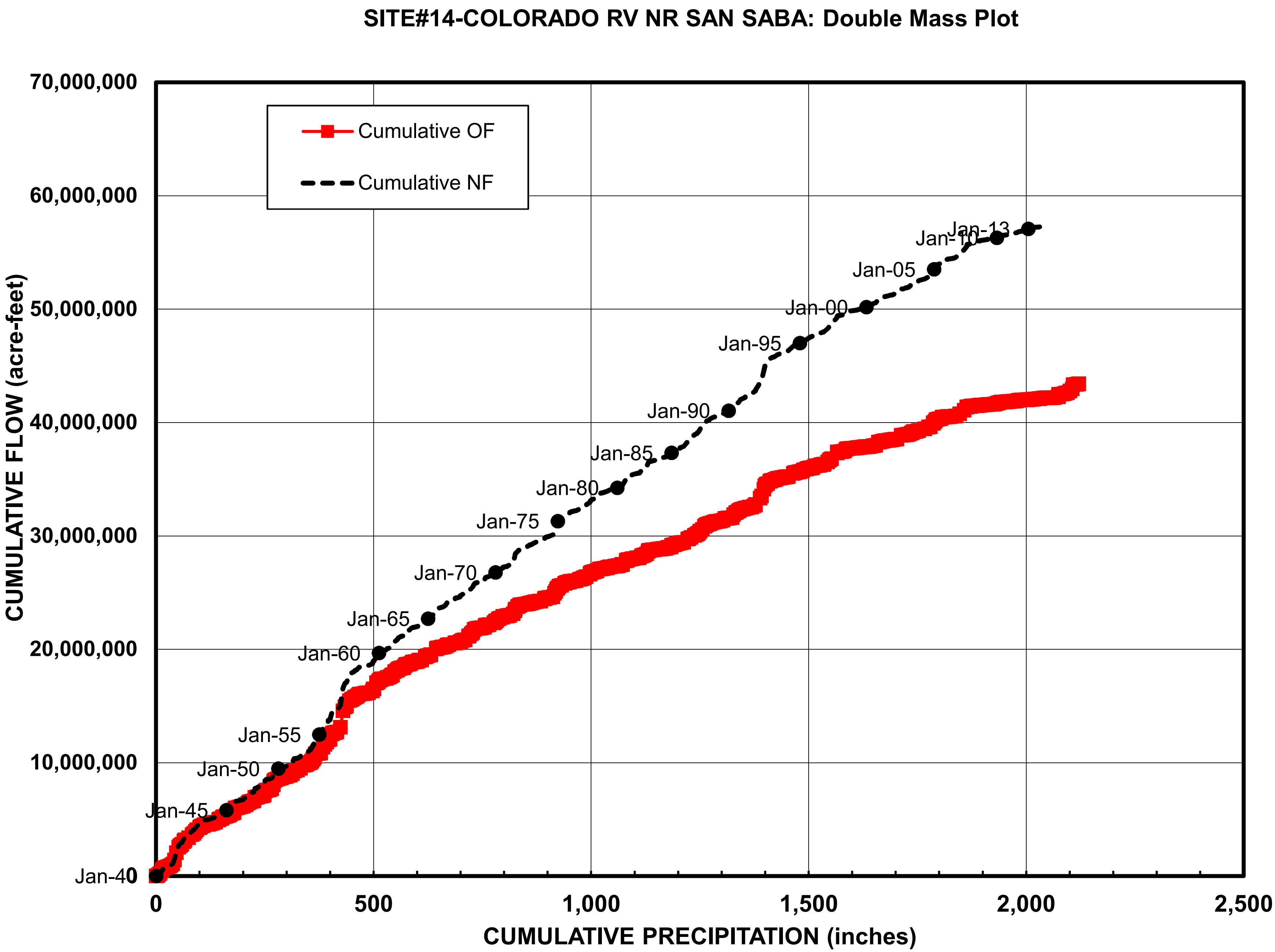



SITE#11-COLORADO RV AT COLORADO CITY: Double Mass Plot
Cumulative OF
Cumulative NF
CUMULATIVE FLOW (acre-feet)
CUMULATIVE PRECIPITATION (inches)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-12

SITE#12-COLORADO RV ABV SILVER: Double Mass Plot




SITE#13-COLORADO RV NR BALLINGER: Double Mass Plot
Cumulative OF
Cumulative NF
CUMULATIVE FLOW (acre-feet)
CUMULATIVE PRECIPITATION (inches)
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13


SITE#14-COLORADO RV NR SAN SABA: Double Mass Plot
Cumulative OF
Cumulative NF
CUMULATIVE FLOW (acre-feet)
0
10,000,000
20,000,000
30,000,000
40,000,000
50,000,000
60,000,000
70,000,000
CUMULATIVE PRECIPITATION (inches)
0
500
1,000
1,500
2,000
2,500
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Jan-10
Jan-13

SUMMARY OF TCEQ DAM SAFETY DATABASE

NORMAL STORAGE CAPACITY OF RESERVOIRS, BY YEAR COMPLETED, BY WAM SUBWATERSHED

(UNITS ARE ACRE-FEET AND ACRES)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
		TOTAL BY WATERSHED					TOTAL BY WATERSHED NOT CONSIDERED IN NAT FLOW PROCESS													
		# OF DAMS AND TOTAL VOLUMES					# OF DAMS AND TOTAL VOLUMES				NORMAL STORAGE BY YEAR COMPLETED									
STUDY SITE NUMBER	WAM WS	TOTAL NUMBER OF DAMS	# OF WITH WATER RIGHTS ASSOCIATED	SURFACE AREA (ACRES)	NORMAL STORAGE (ACRE-FEET)	MAXIMUM STORAGE (ACRE-FEET)	TOTAL NUMBER OF DAMS	SURFACE AREA (ACRES)	NORMAL STORAGE (ACRE-FEET)	MAXIMUM STORAGE (ACRE-FEET)	Before 1940	1940-1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000	After 2000	Total After 1940	Total
	A3	15	4	8,010	202,211	433,688	14	190	1,607	3,088	83	326	103	822	273	0	0	0	1,524	1,607
	A2	1	1	0	76	323	1	0	76	323	76	0	0	0	0	0	0	0	0	76
11	A1	2	1	159	2,634	3,557	2	159	2,634	3,557	48	0	0	2,586	0	0	0	0	2,586	2,634
	B4	1	1	1,560	42,500	90,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B3	19	12	7,075	110,528	301,546	19	7,075	110,528	301,546	6,342	0	54,560	446	341	8,538	40,301	0	104,186	110,528
12	B2	10	1	1,713	32,226	94,683	9	103	742	1,551	225	0	457	30	30	0	0	0	517	742
	B1	1	1	15,100	517,272	1,139,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	C7	1	1	15	80	80	1	15	80	80	80	0	0	0	0	0	0	0	0	80
	C6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C5	2	2	0	162	262	2	0	162	262	162	0	0	0	0	0	0	0	0	162
	C4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	C3	3	0	135	550	550	3	135	550	550	550	0	0	0	0	0	0	0	0	550
	C2	12	9	14,491	316,937	1,819,259	9	177	1,429	1,978	1,027	0	360	42	0	0	0	0	402	1,429
3	C1	17	8	360	2,505	6,506	17	360	2,505	6,506	1,343	193	185	303	481	0	0	0	1,162	2,505
13	D4	42	9	4,571	52,180	177,587	39	1,284	5,970	55,683	172	0	1,469	3,845	468	16	0	0	5,798	5,970
7	D3	13	4	974	12,665	65,337	12	331	4,291	31,837	985	2,447	35	364	60	0	200	200	3,306	4,291
	D2	27	6	19,644	557,345	1,291,611	26	495	3,005	55,798	844	105	0	1,622	434	0	0	0	2,161	3,005
	D1	63	4	986	6,401	100,606	63	986	6,401	100,606	0	0	123	3,691	1,504	1,020	63	0	6,401	6,401
4	E4	2	2	40	420	465	2	40	420	465	280	0	0	0	0	140	0	0	140	420
	E3	1	1	10	53	53	1	10	53	53	53	0	0	0	0	0	0	0	0	53
5	E2	45	4	3,398	35,303	359,502	44	1,378	5,303	147,102	35	101	4,237	930	0	0	0	0	5,268	5,303
6	E1	23	2	484	2,571	30,650	23	484	2,571	30,650	418	40	624	292	876	197	124	0	2,153	2,571
	F3	123	35	11,343	199,749	1,366,376	119	1,198	15,086	197,027	4,317	481	0	8,925	1,293	70	0	0	10,769	15,086
8	F2	51	15	594	5,072	59,761	51	594	5,072	59,761	125	133	0	2,398	2,416	0	0	0	4,947	5,072
14	F1	63	18	1,306	9,244	88,611	63	1,306	9,244	88,611	1,174	276	2,714	1,469	3,161	450	0	0	8,070	9,244
	G5	1	1	7	62	62	1	7	62	62	0	0	0	62	0	0	0	0	62	62
	G4	3	1	27	809	809	3	27	809	809	197	0	0	300	312	0	0	0	612	809
	G3	2	1	10	252	324	2	10	252	324	252	0	0	0	0	0	0	0	0	252
	G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	G1	5	3	191	894	1,069	5	191	894	1,069	383	0	317	44	90	0	60	0	511	894
	H2	1	1	0	100	100	1	0	100	100	0	0	0	100	0	0	0	0	100	100
10	H1	9	5	130	987	7,590	9	130	987	7,590	124	0	0	732	131	0	0	0	863	987
	I4	6	5	23,209	993,574	1,183,373	5	149	1,574	3,373	0	0	830	0	189	0	0	555	1,574	1,574
	I3	2	1	18	242	510	2	18	242	510	0	187	0	55	0	0	0	0	242	242
	I2	38	15	8,348	163,450	304,029	35	231	2,797	8,769	144	58	14	1,143	466	670	302	0	2,653	2,797
Study Area Tot		604	174	123,908	3,269,054	8,928,279	583	17,083	185,446	1,109,640	19,439	4,347	66,028	30,201	12,525	11,101	41,050	755	166,007	185,446

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NUMBER OF WATER BODIES BY MAP WATERSHED, BY SIZE OF WATER SURFACE AREA

After Major Reservoirs that were Adjusted for in Naturalized Flow Process were Removed

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	MAP ID	NHD WATER BODY COVERAGE (2003 DATASET)											
		TOTAL		NUMBER OF WATER BODIES BY SIZE OF WATER SURFACE AREA									
		# OF WATER BODIES	COMB. SURFACE AREA (ACRES)	No Area Given (1)	Specified as Less Than 1 acre	BTWN 1 and 5 acres	BTWN 5 and 10 acres	BTWN 10 and 15 acres	BTWN 15 and 20 acres	BTWN 20 and 30 acres	BTWN 30 and 60 acres	BTWN 60 and 100 acres	GT 100 acres
(1)	A3	3,892	6,236	547	2,683	458	107	39	14	15	21	3	5
(2)	A2	492	253	67	387	34	3	1	0	0	0	0	0
(3)	A1	540	483	50	436	50	1	0	0	2	0	0	1
(4)	B4	206	120	25	163	15	2	1	0	0	0	0	0
(5)	B3	7,557	30,781	1,485	4,005	1,203	418	162	70	101	67	21	25
(6)	B2	1,919	1,485	237	1,488	149	26	6	7	4	0	2	0
(7)	B1	819	337	125	661	25	6	2	0	0	0	0	0
(8)	C7	849	833	174	578	75	8	4	2	4	3	1	0
(9)	C6	2,277	6,099	538	1,351	200	65	39	31	23	14	11	5
(10)	C5	178	230	40	114	11	6	4	2	1	0	0	0
(11)	C4	125	61	36	75	13	1	0	0	0	0	0	0
(12)	C3	273	157	64	180	25	3	1	0	0	0	0	0
(13)	C2	819	858	117	574	96	20	5	1	4	1	1	0
(14)	C1	1,759	1,293	335	1,235	153	21	7	4	2	0	2	0
(15)	D4	4,016	2,641	800	2,889	259	27	10	13	12	5	1	0
(16)	D3	2,852	1,631	545	2,068	214	14	4	3	1	2	0	1
(17)	D2	3,202	1,638	668	2,357	148	14	2	3	5	5	0	0
(18)	D1	6,860	4,231	1,325	4,992	435	50	26	13	11	7	1	0
(19)	E4	748	828	184	452	75	19	9	1	6	2	0	0
(20)	E3	742	418	139	549	43	6	2	2	1	0	0	0
(21)	E2	1,384	1,605	268	968	104	11	7	4	10	11	1	0
(22)	E1	3,165	1,746	835	2,119	161	28	8	8	3	2	1	0
(23)	F3	12,882	8,421	2,099	9,546	1,049	109	35	14	15	12	1	2
(24)	F2	3,210	2,607	505	2,373	257	29	17	12	10	7	0	0
(25)	F1	6,788	4,293	1,334	4,952	406	40	18	13	16	7	2	0
(26)	G5	600	695	137	339	91	20	8	3	1	1	0	0
(27)	G4	666	585	182	395	72	7	4	1	4	1	0	0
(28)	G3	2,182	1,006	664	1,375	125	8	5	2	2	1	0	0
(29)	G2	406	153	117	260	27	2	0	0	0	0	0	0
(30)	G1	3,864	1,293	1,377	2,347	129	7	1	1	0	0	2	0
(31)	H2	916	552	162	642	105	4	1	1	1	0	0	0
(32)	H1	2,342	1,290	462	1,661	199	12	4	1	2	1	0	0
(33)	I4	1,972	1,038	461	1,332	164	10	2	0	2	0	1	0
(34)	I3	1,005	508	237	679	80	7	0	1	1	0	0	0
(35)	I2	5,403	2,502	1,508	3,510	336	30	8	5	4	2	0	0
TOTAL (2)		86,910	88,908	17,849	59,735	6,986	1,141	442	232	263	172	51	39
TOTAL (3)		42,253	25,352	9,897	28,945	2,809	290	120	68	74	42	8	0

(1) Water body features in column 5 were depicted and thus counted in the NHD Small Water Body coverage; however, the GIS coverage attributes specified their water surface area as zero. It should be noted that the smallest water surface area stated for any water body in the coverage was 0.001 square KM (0.247 acres), thus these water bodies appear to have had a water surface area below the 0.001 square KM threshold.

(2) Total for Entire Physical Upper Colorado River Basin Upstream of Mansfield Dam (I2).

(3) Total for Portion of Upper Colorado River Basin below Colorado River at Stacy (D2) and Pecan Bayou near Brownwood (F3) to Colorado River at Mansfield Dam (I2).

NUMBER OF ACRES CULTIVATED (ALL CROPS COMBINED)

COUNTIES COVERING THE MAJOR PORTION OF STUDY SITE WATERSHEDS

YEAR	BLANCO	BORDEN	BROWN	BURNET	COKE	COLEMAN	CONCHO	GILLESPIE	GLASSCOCK	HOWARD	LAMPASAS	MASON	MCCULLOCH	MENARD	MILLS	MITCHELL	REAGAN	RUNNELS	SAN SABA	SCHLEICHER	STERLING	TOM GREEN	TRAVIS
1968	15,800	24,340	89,800	31,200	28,720	209,800	164,800	62,400	30,380	91,700	45,100	18,460	124,560	15,600	49,050	90,500	5,900	275,500	52,240	25,000	2,980	144,000	81,900
1969	18,400	30,200	76,850	21,400	28,800	237,600	132,000	69,500	33,750	104,330	38,300	13,850	131,000	9,500	47,850	89,000	6,200	280,400	49,000	18,400	3,100	139,100	87,400
1970	13,700	30,500	72,620	24,330	37,520	161,000	126,100	68,250	36,100	98,800	43,000	14,820	110,250	9,000	40,190	87,300	7,300	226,600	57,000	21,850	2,700	142,700	78,900
1971	12,400	32,400	80,900	22,930	34,800	191,500	124,100	52,600	34,500	105,700	38,200	13,100	118,200	11,800	43,150	94,700	9,050	256,100	42,900	19,000	5,100	148,200	73,500
1972	10,900	25,000	63,750	20,700	38,550	176,200	118,100	59,000	44,800	103,000	34,200	8,700	112,000	12,500	30,550	99,900	10,250	223,900	48,600	23,700	6,400	124,000	82,200
1973	10,600	27,400	56,400	24,300	32,570	195,600	147,200	46,800	40,000	101,500	34,800	9,600	137,000	12,800	30,500	98,900	11,200	246,700	37,400	22,650	5,600	131,000	75,900
1974	9,100	26,200	73,030	24,400	35,300	192,200	155,500	54,600	39,300	93,700	34,500	10,700	117,100	14,600	38,500	92,800	14,800	269,700	55,500	25,000	7,000	143,400	90,300
1975	11,000	31,100	65,600	19,600	33,700	244,550	182,200	59,700	54,600	101,400	34,000	8,800	116,300	13,000	23,200	108,700	20,900	292,100	51,100	22,850	7,200	145,800	73,000
1976	7,900	36,350	63,600	21,800	34,800	223,500	158,200	51,100	58,400	110,200	26,900	11,100	140,500	11,500	25,600	113,100	24,300	322,800	47,800	28,600	8,000	162,100	84,700
1977	10,500	43,100	52,550	14,700	38,500	213,400	178,300	48,850	56,400	110,200	27,700	10,300	117,000	14,950	28,800	109,000	26,000	309,100	53,300	40,500	10,700	164,000	90,600
1978	10,300	39,900	62,400	20,700	38,500	214,900	184,500	58,000	64,900	117,500	32,000	8,100	125,200	14,300	33,700	105,800	30,000	309,700	59,500	30,200	7,300	151,400	106,700
1979	7,600	38,100	55,000	14,800	40,900	172,600	158,100	49,600	71,300	118,500	26,000	8,100	104,750	16,300	25,700	108,400	34,900	295,700	40,900	33,200	7,000	168,700	105,300
1980	7,900	36,200	65,300	12,400	31,700	195,900	167,800	52,700	73,100	116,100	31,200	5,700	113,500	19,200	27,900	99,600	32,200	294,100	41,300	29,800	5,800	152,400	110,200
1981	7,600	39,300	54,000	12,800	31,200	216,400	170,900	47,700	84,900	120,300	27,800	2,400	125,500	9,300	26,100	109,800	37,000	323,900	46,500	40,100	4,500	153,200	124,100
1982	8,300	31,200	63,800	16,100	35,600	189,100	184,500	63,100	80,800	110,000	32,700	2,800	161,500	11,300	29,800	94,600	37,800	321,700	40,700	35,200	5,200	176,600	101,300
1983	7,200	22,100	40,900	10,600	24,300	200,500	147,700	49,000	68,800	78,400	23,800	5,300	150,500	5,700	21,900	67,000	24,800	350,200	29,900	35,300	4,000	131,200	104,000
1984	3,300	29,700	41,900	8,600	31,900	178,900	143,200	40,200	70,500	110,400	31,000	5,700	148,600	5,200	23,200	79,700	32,900	387,400	30,200	23,400	8,800	160,900	107,900
1985	2,500	28,900	49,000	6,500	33,700	239,400	165,200	32,200	78,100	111,700	19,600	5,600	104,500	5,600	21,700	87,000	28,500	347,800	36,700	24,400	10,400	139,500	102,200
1986	2,700	34,400	63,200	10,000	43,900	193,300	130,600	38,600	91,200	135,700	16,400	7,400	128,600	8,900	22,200	90,700	29,300	356,200	48,500	27,200	7,200	143,600	74,200
1987	3,500	35,700	67,300	9,700	62,600	161,300	164,800	36,700	75,200	111,900	16,600	10,000	158,800	7,500	23,300	83,900	34,300	326,900	56,000	30,400	12,200	155,300	83,000
1988	5,000	34,800	69,500	8,000	49,400	174,500	138,300	34,600	78,800	104,900	18,200	7,000	123,700	7,000	25,600	83,500	35,700	292,500	36,000	25,400	8,600	159,200	78,100
1989	2,700	31,500	72,900	7,600	42,400	194,400	164,900	32,600	70,500	92,500	22,800	6,400	112,400	7,200	25,200	80,000	31,700	272,200	39,600	26,500	19,500	146,400	79,800
1990	3,000	33,000	73,500	8,700	40,200	184,800	156,900	36,000	81,000	100,600	23,200	11,200	126,800	7,800	29,700	75,200	35,800	278,400	48,800	28,200	15,800	155,000	77,600
1991	3,800	34,200	78,300	9,100	26,900	164,400	151,100	40,900	84,800	113,300	21,100	12,600	127,800	13,800	31,500	75,600	37,600	259,700	56,300	26,700	11,600	160,100	78,700
1992	4,500	37,100	72,600	5,400	23,700	162,500	137,900	36,300	76,400	128,600	19,600	9,000	117,000	7,200	26,300	73,000	34,600	225,000	56,100	25,300	11,800	157,300	80,400
1993	6,100	36,800	79,300	7,000	23,400	167,200	128,300	43,400	79,700	100,300	24,000	15,400	115,500	12,000	33,500	85,300	36,400	239,800	54,800	25,500	15,600	161,800	77,800
1994	5,800	35,100	87,400	8,300	28,500	183,700	132,500	44,900	79,700	104,400	20,800	17,000	119,400	10,600	36,800	84,300	34,700	266,100	50,500	26,700	19,200	164,900	67,700
1995	4,700	36,700	85,000	5,900	25,500	167,300	133,300	42,100	82,800	108,200	20,100	16,000	122,300	7,000	34,500	87,500	36,100	267,000	54,400	31,200	16,800	173,600	65,000
1996	4,800	66,600	81,600	6,600	35,000	183,100	129,500	50,100	100,700	162,400	27,100	11,200	136,300	7,400	33,300	83,400	43,300	278,600	56,900	27,900	15,600	174,100	71,300
1997	4,200	40,500	88,900	6,100	21,600	181,700	130,900	57,200	94,300	108,100	17,700	6,500	106,600	9,400	27,700	86,200	37,500	254,700	60,700	34,600	8,000	186,000	59,100
1998	1,800	33,400	78,400	9,200	21,900	153,400	121,700	56,800	148,400	210,500	11,900	9,000	106,100	7,000	26,900	109,100	53,000	268,600	51,700	29,100	15,400	192,800	52,700
1999	2,400	27,100	80,200	4,800	28,300	161,700	133,900	45,800	123,600	135,200	16,700	11,200	107,500	8,600	27,500	104,100	54,100	280,200	49,400	26,700	14,000	168,200	48,400
2000	2,100	37,200	45,100	2,700	31,000	117,800	192,100	27,000	260,900	288,600	11,500	15,600	115,300	3,600	19,100	140,700	122,000	375,100	38,600	47,100	11,200	389,500	52,600
2001		45,400	47,500	1,500	39,600	118,200	160,600	25,200	255,000	217,700	10,900	17,000	105,400	6,200	18,000	120,800	80,200	286,200	45,200	44,900	18,600	231,000	33,400
2002		41,300	54,500	4,200	32,500	148,000	150,600	24,400	175,800	170,200	12,500	16,600	110,500	6,400	22,200	107,800	74,000	331,300	28,800	34,800	16,000	241,900	49,300
2003		40,400	47,200	1,300	36,600	147,600	154,100	27,200	136,000	131,500	12,400	15,800	115,400	10,800	20,000	109,400	76,600	323,600	48,600	46,800	17,400	238,300	48,900
2004		33,800	46,000	1,800	37,500	151,300	148,800	26,900	127,900	131,900	13,200	14,200	110,400	9,000	15,500	115,000	65,700	307,200	47,100	37,100	17,000	203,400	48,400
2005		50,600	37,700	1,600	31,500	128,100	137,300	27,800	123,600	131,200	11,700	11,100	102,200	8,600	11,000	108,500	56,200	249,500	48,400	32,600	13,500	199,800	40,300
2006	1,500	52,100	35,700	2,200	21,600	128,200	142,700	24,200	108,900	135,000	8,400	6,800	104,800	6,800	12,900	108,500	55,300	296,700	33,400	25,900	13,700	215,400	39,500
2007	1,100	29,000	32,800	2,000	23,500	105,500	139,600	23,300	143,300	112,300		6,600	98,200		14,600	123,000	66,000	303,900	26,200	26,300		225,100	32,600
2008		32,000	21,300		12,100	62,400	83,400	12,900	149,400	126,800	6,900		42,700		11,500	86,900	36,300	189,900	22,400			165,000	29,200
2009		56,800				63,400	96,900		120,700	138,800	6,700		50,800		13,500	90,800	48,300	200,300		17,800		187,700	27,400
2010		47,200	9,100		13,600	66,900	89,600	14,400	109,900	117,500	6,500		47,200		3,000	89,000	46,900	200,300	17,500	20,700		170,800	32,800
2011			9,400			48,400	41,000	5,800	115,100				37,200		11,300	72,400	46,800	132,200	14,900			183,000	17,400
2012		45,400	14,600		8,300	49,400	80,900	13,000	111,800		6,200		37,700	2,700	10,900	64,300	41,500	197,000	16,700	11,800		165,700	29,000
2013		50,300	19,400		11,000	57,700	95,500	8,600	131,300	154,500			46,700		7,400	62,600	40,100	206,100	18,100	4,400		180,200	32,100
2014		43,300	18,800		12,300	70,900	91,900	7,300	106,900	142,200	2,100	1,100	53,400		10,500	66,500	57,000	209,100	17,200	17,900		176,700	29,400
2015		41,100	11,100		12,100	78,000	85,600	12,600	108,900	141,300	7,300	900	55,300	4,000	11,200	62,900	51,000	210,100	20,300	20,400		173,900	26,800
2016			17,500		10,700	61,600	63,700	10,800	10,400	8,400	5,800		38,200	3,800	11,300			136,700		7,200		86,600	25,100
AVERAGE	6,706	36,910	55,692	11,289	30,176	156,934	137,088	38,598	93,541	122,722	21,285	9,970	106,901	9,415	24,394	93,056	39,417	272,541	42,205	27,367	10,525	171,643	66,696
MAXIMUM	18,400	66,600	89,800	31,200	62,600	244,550	192,100	69,500	260,900	288,600	45,100	18,460	161,500	19,200	49,050	140,700	122,000	387,400	60,700	47,100	19,500	389,500	124,100
MINIMUM	1,100	22,100	9,100	1,300	8,300	48,400	41,000	5,800	10,400	8,400	2,100	900	37,200	2,700	3,000	62,600	5,900	132,200	14,900	4,400	2,700	86,600	17,400

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NUMBER OF WELLS DRILLED, BY WATERSHED, BY YEAR, FROM TWDB'S SDRDB (SUBMITTED DRILLERS REPORTS DATABASE)

MAP	YEAR DRILLED																				TOTAL
WATERSHED	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
A3	3	0	0	0	0	132	180	160	161	140	132	162	173	225	163	304	161	230	253	59	2,638
A2	0	0	0	0	0	4	38	16	20	41	33	23	19	17	15	34	37	34	7	7	345
A1	0	0	0	0	0	7	0	13	32	8	9	47	20	18	53	38	37	44	29	17	372
B4	0	0	0	0	0	0	3	15	36	25	18	19	21	22	17	61	74	60	31	30	432
B3	3	0	0	0	12	234	810	1,453	1,682	1,800	1,719	1,702	2,070	1,612	1,892	2,958	3,972	3,220	3,048	1,321	29,508
B2	0	0	0	0	0	3	48	19	91	14	57	8	31	14	27	74	72	69	41	31	599
B1	0	0	0	0	0	0	9	35	17	24	17	17	14	18	10	33	26	25	15	3	263
C7	0	0	0	0	0	8	8	22	33	29	20	31	50	32	115	159	145	130	56	26	864
C6	0	0	0	0	10	14	87	64	92	88	120	154	166	118	228	478	388	456	585	165	3,213
C5	0	0	0	0	0	1	21	16	24	5	19	32	26	28	23	40	95	116	57	14	517
C4	0	0	0	0	0	0	7	8	8	17	7	5	2	4	7	6	7	13	6	1	98
C3	0	0	0	0	0	1	33	13	17	17	23	17	8	10	8	9	11	14	16	5	202
C2	0	0	0	0	0	11	76	120	108	85	120	103	100	71	83	83	119	123	136	42	1,380
C1	0	0	0	0	0	3	41	135	122	143	200	84	170	114	116	149	140	185	182	70	1,854
D4	0	0	0	0	0	0	2	45	53	42	59	84	59	77	41	55	68	82	85	48	800
D3	0	0	0	0	0	0	2	9	12	5	9	28	22	21	15	43	20	21	19	9	235
D2	0	0	0	0	0	4	9	23	25	16	10	40	28	37	28	31	38	36	24	22	371
D1	0	0	0	0	0	0	1	4	4	10	19	10	13	12	6	41	12	10	5	7	154
E4	1	0	0	0	0	1	11	20	15	25	24	13	21	22	25	25	30	21	18	8	280
E3	0	0	0	0	0	2	19	33	20	14	10	46	19	20	20	21	22	19	15	18	298
E2	0	0	4	0	0	10	9	37	42	25	38	20	13	9	18	67	77	66	62	9	506
E1	0	0	0	0	0	9	16	34	26	12	31	29	26	55	23	44	37	39	44	16	441
F3	0	0	0	0	0	12	32	61	69	43	52	50	43	56	64	97	84	93	72	61	889
F2	0	0	0	0	0	7	8	49	35	17	27	27	24	39	23	27	26	33	30	14	386
F1	0	0	0	0	0	7	12	40	33	29	46	37	28	28	15	68	32	34	29	10	448
G5	0	0	0	0	0	1	17	11	29	16	26	12	34	36	19	24	23	25	32	17	322
G4	0	0	0	0	0	6	28	28	25	29	49	61	29	28	25	18	14	17	27	14	398
G3	0	0	0	0	6	42	76	85	100	113	95	91	119	141	83	83	72	65	76	46	1,293
G2	0	0	0	0	0	8	10	13	9	11	8	14	16	9	10	15	14	11	22	11	181
G1	0	0	0	0	0	88	85	85	77	101	126	92	60	77	72	137	97	112	132	84	1,425
H2	0	0	0	0	0	44	62	89	78	63	85	67	59	65	47	54	43	44	63	47	910
H1	0	0	0	0	0	57	117	100	129	164	164	140	116	84	98	140	98	131	104	83	1,725
I4	0	0	0	0	0	14	22	59	64	54	75	73	44	74	39	67	95	50	56	24	810
I3	0	0	0	0	0	21	28	29	44	34	73	50	33	34	15	34	39	33	28	16	511
I2	0	0	0	1	2	95	279	402	441	449	659	370	514	314	232	432	338	352	406	256	5,542
TOTAL	7	0	4	1	30	846	2206	3345	3773	3708	4179	3758	4190	3541	3675	5949	6563	6013	5811	2611	60,210

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COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 1]																
	1980	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
BLANCO																	
1 EDWARDS-TRINITY-PLATEAU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
2 ELLENBURGER-SAN SABA	512	763	878	901	958	1161	1045	1048	1104	1100	971	1101	1079	1072	1084	1114	889
3 HICKORY	-	-	-	-	-	-	-	-	-	-	64	68	68	68	68	68	46
4 MARBLE FALLS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
5 OTHER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
6 TRINITY	374	332	355	374	390	391	466	477	512	521	520	557	503	520	526	542	431
7 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BORDEN																	
1 DOCKUM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
2 EDWARDS-TRINITY-HIGH PLAINS	-	86	105	99	97	65	64	54	54	80	4	4	3	3	3	3	6
3 OGALLALA	449	754	912	880	861	569	550	475	475	686	910	1300	4344	8254	2869	2267	1600
4 OTHER	131	287	301	295	284	262	264	1076	1077	1061	1074	1044	1042	1025	923	1041	450
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BROWN																	
1 ELLENBURGER-SAN SABA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
2 OTHER	244	218	455	426	392	53	173	105	128	108	104	126	155	102	88	78	106
3 TRINITY	805	975	1895	1831	1920	2525	1438	1232	1303	2144	1951	2376	2303	2441	2714	3799	2642
4 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BURNET																	
1 EDWARDS-BFZ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
2 EDWARDS-TRINITY-PLATEAU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 ELLENBURGER-SAN SABA	815	174	1002	906	320	430	572	561	572	602	643	712	739	907	970	886	750
4 HICKORY	45	220	144	145	141	81	94	95	119	199	283	234	239	250	261	244	197
5 MARBLE FALLS	38	21	18	14	14	13	73	64	64	71	70	81	84	91	97	88	97
6 OTHER	38	163	170	162	177	159	162	379	270	563	366	431	418	421	202	418	760
7 TRINITY	1186	2350	1338	1369	1341	1146	1044	921	881	866	856	867	849	1077	1153	1090	1289
8 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
COKE																	
1 EDWARDS-TRINITY-PLATEAU	88	18	13	12	11	17	20	24	30	30	29	26	26	28	28	26	90
2 OTHER	363	855	820	800	777	760	658	558	366	789	721	693	770	680	1509	675	865
3 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
COLEMAN																	
1 ELLENBURGER-SAN SABA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
2 OTHER	139	167	122	115	116	77	78	80	84	84	79	77	134	87	83	86	101
3 TRINITY	118	43	39	39	40	35	35	38	29	29	27	26	45	29	28	29	29
4 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CONCHO																	
1 EDWARDS-TRINITY-PLATEAU	267	174	169	226	191	191	186	193	255	270	211	221	188	206	199	202	145
2 HICKORY	325	213	228	221	279	280	471	380	537	496	557	477	475	510	518	553	452
3 LIPAN	400	3088	2466	3133	2666	3011	2193	2797	2774	5814	3661	5037	3757	1358	3353	4705	1445
4 OTHER	544	351	343	431	361	360	391	401	526	559	439	450	403	444	432	436	1280

COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 1]																
	1980	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GILLESPIE																	
1 EDWARDS-TRINITY-PLATEAU	6	6	7	3	7	7	7	11	13	13	13	15	13	13	15	16	382
2 ELLENBURGER-SAN SABA	2635	5124	3386	2566	2460	4196	3922	3966	3981	4687	2950	3084	3315	2994	3403	3238	3829
3 HICKORY	93	83	67	66	72	84	102	98	103	107	233	235	265	229	242	166	538
4 MARBLE FALLS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 OTHER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89
6 TRINITY	1508	2094	1522	1373	1344	1763	1700	1752	1889	2013	3262	3254	3723	3142	3277	2333	1672
7 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GLASSCOCK																	
1 EDWARDS-TRINITY-PLATEAU	38017	24186	47199	39383	29703	30976	27001	35436	24652	39172	50126	59260	47638	45307	53728	21343	30819
2 OGALLALA	2426	415	766	649	498	516	453	587	409	637	8227	9735	7821	7437	8824	3494	4592
3 OTHER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	363
4 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HOWARD																	
1 DOCKUM	169	526	514	477	163	151	151	127	125	124	133	99	98	105	112	125	337
2 EDWARDS-TRINITY-PLATEAU	510	901	874	788	542	712	576	505	724	597	787	888	769	718	555	810	2383
3 OGALLALA	2025	3169	3209	2168	2253	2715	3415	3167	4805	2007	2276	2136	2168	3274	4242	5602	3127
4 OTHER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	334
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LAMPASAS																	
1 ELLENBURGER-SAN SABA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	76
2 MARBLE FALLS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60
3 OTHER	62	82	70	80	111	91	163	181	137	89	87	87	85	85	84	85	73
4 TRINITY	1146	1154	1214	591	499	563	821	926	1109	1064	1069	1067	1083	1057	1045	1244	1181
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LLANO																	
1 ELLENBURGER-SAN SABA	54	111	120	105	119	105	117	115	101	88	92	90	90	82	83	86	180
2 HICKORY	1156	1018	1230	870	799	1223	1171	1259	1065	1355	1527	1391	1388	1388	1389	1388	808
3 OTHER	731	789	890	838	886	813	835	855	663	642	752	745	707	698	710	716	1097
4 TRINITY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MASON																	
1 EDWARDS-TRINITY-PLATEAU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
2 ELLENBURGER-SAN SABA	41	127	138	132	124	123	135	139	165	149	132	135	134	134	136	144	121
3 HICKORY	16779	17150	16846	15516	19029	18654	17812	18223	13238	14366	13506	12489	11528	10186	9984	9994	10854
4 MARBLE FALLS	41	150	159	152	144	144	131	135	160	144	127	130	129	129	131	137	73
5 OGALLALA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 OTHER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	329
7 TRINITY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MCCULLOCH																	

COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 1]																
	1980	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1 EDWARDS-TRINITY-PLATEAU	36	28	29	27	30	27	29	31	36	17	16	16	13	15	14	14	17
2 ELLENBURGER-SAN SABA	442	324	291	245	266	260	259	271	422	378	351	355	289	327	306	300	394
3 HICKORY	7885	7495	7058	6638	6233	6522	5720	5433	5090	6344	6351	6074	5343	5397	5688	5321	6530
4 MARBLE FALLS	30	22	22	20	22	21	22	21	27	16	15	15	12	14	13	13	48
5 OTHER	182	191	112	126	132	164	142	139	187	185	178	178	156	167	159	164	183
6 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MENARD																	
1 EDWARDS-TRINITY-PLATEAU	582	379	528	488	468	423	465	508	651	623	1020	966	866	851	793	983	776
2 ELLENBURGER-SAN SABA	7	5	5	5	5	5	5	5	6	6	7	6	6	6	5	5	4
3 HICKORY	9	10	52	41	35	25	35	44	59	52	0	-	-	-	-	-	74
4 OTHER	111	102	373	303	261	200	262	321	425	381	47	43	41	39	36	36	211
5 TRINITY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MILLS																	
1 ELLENBURGER-SAN SABA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	98
2 OTHER	101	182	193	189	193	203	198	215	229	228	227	241	349	228	220	245	195
3 TRINITY	1184	622	806	838	818	660	1047	1093	1141	772	750	791	1111	728	716	772	596
4 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MITCHELL																	
1 DOCKUM	3607	5260	3590	2966	2825	2134	2245	2654	1424	1799	1727	791	1558	1336	1346	3376	6545
2 OTHER	4	3	3	3	3	4	4	4	2	2	2	2	2	2	2	2	2
3 PECOS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
4 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NOLAN																	
1 DOCKUM	2016	1947	1311	1191	1548	2160	1921	1649	1305	2250	2228	1647	2707	1757	1684	1818	3601
2 EDWARDS-TRINITY-PLATEAU	1260	1197	823	347	818	1454	1425	1253	587	790	449	524	499	209	214	203	800
3 OGALLALA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4 OTHER	434	560	464	427	430	481	469	487	461	562	689	498	701	513	489	508	1583
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RUNNELS																	
1 EDWARDS-TRINITY-PLATEAU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
2 LIPAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	147
3 OTHER	2027	2640	2091	2090	2592	1977	1866	4639	2504	2420	1859	2263	3417	2716	2374	1830	709
4 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAN SABA																	
1 ELLENBURGER-SAN SABA	371	360	418	362	386	379	358	368	386	488	372	371	520	397	368	350	492
2 HICKORY	2056	2081	1139	1098	1028	1261	997	1106	646	1081	1066	1126	1352	1575	658	1517	736
3 MARBLE FALLS	1241	948	788	532	592	636	564	529	442	471	1312	1375	1422	1410	1137	1328	1458
4 OTHER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	83
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SCHLEICHER																	
1 EDWARDS-TRINITY-PLATEAU	2350	2476	2427	1575	1774	2696	2113	2220	2457	2741	3089	2660	2879	2854	3773	4300	3263

COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 1]																
	1980	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
2 OTHER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SCURRY																	
1 DOCKUM	8762	5676	5039	4350	4145	3154	3475	6501	4707	5387	5034	3833	5265	4468	3987	6385	3350
2 OTHER	1081	321	274	232	227	197	297	678	395	471	260	282	283	268	189	166	125
3 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
STERLING																	
1 DOCKUM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
2 EDWARDS-TRINITY-PLATEAU	978	1047	867	713	791	851	873	1170	1229	1156	1011	963	913	951	950	937	453
3 OTHER	1267	1383	940	556	628	944	941	895	901	656	848	845	900	887	939	929	720
4 PECOS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	63
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TAYLOR																	
1 EDWARDS-TRINITY-PLATEAU	347	95	90	88	61	62	61	72	152	113	62	73	69	65	7	66	116
2 OTHER	2544	1607	1417	1076	1211	1044	827	1569	3656	1435	1284	1479	1499	1289	1069	4298	522
3 SEYMOUR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
4 TRINITY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOM GREEN																	
1 BLAINE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
2 EDWARDS-TRINITY-PLATEAU	388	433	413	513	505	611	589	610	658	706	1074	1177	939	1087	847	762	391
3 LIPAN	9721	16565	14867	11401	20006	21372	22395	17715	11076	58053	56920	71143	31473	64934	35877	20958	19004
4 OTHER	5159	9172	8249	6463	11217	12014	5292	4296	2862	13082	8581	10457	5098	9666	5520	3751	2739
5 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TRAVIS																	
1 EDWARDS-BFZ	1599	4662	3949	4984	5189	5035	5161	5215	5521	6629	6482	7066	7224	6916	8257	7383	11270
2 OTHER	672	2264	1062	1054	503	1063	1252	1668	2163	1756	1471	1624	1527	1578	1488	1299	1502
3 TRINITY	2691	2609	1279	1413	1372	1142	3019	3172	3578	3286	2594	2715	1863	1617	1779	1720	1868
4 UNKNOWN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Yellow Shade Represents Year of Maximum Use

COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 2]																	
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	AVG	MAX	% MAX is of AVG	YEAR OF MAX
BLANCO																		
1 EDWARDS-TRINITY-PLATEAU	2	2	1	1	2	2	2	3	4	2	1	1	1	1	2	4		2009
2 ELLENBURGER-SAN SABA	885	867	848	408	460	636	664	679	983	525	545	1565	1339	1377	921	1,565	170%	2012
3 HICKORY	44	47	34	36	49	102	125	126	195	143	149	349	301	307	117	349	298%	2012
4 MARBLE FALLS	2	2	1	1	2	8	7	9	11	10	10	9	8	8	6	11	183%	2009
5 OTHER	8	9	6	7	10	40	37	43	50	45	48	45	40	39	29	50	172%	2009
6 TRINITY	364	343	283	122	167	559	563	1076	1137	1417	1761	1846	1734	2109	686	2,109	307%	2014
7 UNKNOWN	-	-	-	581	637	-	-	0	0	0	0	-	-	-	203	637	314%	2005
BORDEN																		
1 DOCKUM	6	6	6	6	19	50	47	45	40	37	39	35	29	26	26	50	189%	2006
2 EDWARDS-TRINITY-HIGH PLAINS	6	5	6	6	19	16	19	14	13	15	15	13	9	9	30	105	352%	1986
3 OGALLALA	1684	1951	1819	2008	2318	2068	2122	1964	3415	1385	3280	2936	3478	1678	1,944	8,254	425%	1997
4 OTHER	462	515	490	525	584	502	524	490	752	374	715	652	748	404	625	1,077	172%	1992
5 UNKNOWN	-	-	-	-	-	-	-	100	114	128	57	78	94	93	95	128	135%	2010
BROWN																		
1 ELLENBURGER-SAN SABA	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	1	214%	2005
2 OTHER	88	100	85	70	88	133	119	147	189	198	205	180	158	106	159	455	286%	1986
3 TRINITY	2015	2242	1801	632	710	422	404	1335	1854	639	775	1329	876	1033	1,625	3,799	234%	1999
4 UNKNOWN	-	-	-	-	-	-	-	427	446	465	433	-	-	-	443	465	105%	2010
BURNET																		
1 EDWARDS-BFZ	16	-	7	3	-	-	-	6	9	9	6	1	1	0	7	16	238%	2000
2 EDWARDS-TRINITY-PLATEAU	-	-	-	7	-	-	-	-	-	-	-	-	-	-	7	7	100%	2004
3 ELLENBURGER-SAN SABA	443	448	2061	419	2167	1104	806	1117	1199	1541	1497	1484	1174	999	904	2,167	240%	2005
4 HICKORY	267	275	286	179	248	301	201	152	132	229	201	268	201	176	197	301	153%	2006
5 MARBLE FALLS	125	120	120	119	157	141	126	142	178	164	161	155	154	136	97	178	184%	2009
6 OTHER	877	958	451	472	514	511	329	342	329	644	641	582	635	858	432	958	222%	2002
7 TRINITY	1285	1309	1431	1399	1470	1433	1195	1076	1196	2141	2099	2265	1567	1377	1,318	2,350	178%	1985
8 UNKNOWN	-	-	-	-	-	-	-	1612	1673	1734	1575	-	-	-	1,649	1,734	105%	2010
COKE																		
1 EDWARDS-TRINITY-PLATEAU	92	101	62	83	140	153	121	159	138	160	189	164	125	117	75	189	253%	2011
2 OTHER	859	1028	485	915	962	1156	816	974	695	1148	1159	811	738	744	811	1,509	186%	1998
3 UNKNOWN	-	-	-	-	-	-	-	28	62	96	241	5	54	10	71	241	340%	2011
COLEMAN																		
1 ELLENBURGER-SAN SABA	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	300%	2000
2 OTHER	100	94	76	98	41	46	47	42	61	76	47	107	77	79	87	167	192%	1985
3 TRINITY	28	26	21	-	-	-	-	-	-	-	-	-	-	-	37	118	322%	1980
4 UNKNOWN	-	-	-	-	-	-	-	28	30	33	53	1	2	-	25	53	216%	2011
CONCHO																		
1 EDWARDS-TRINITY-PLATEAU	141	144	116	303	195	258	306	219	220	203	201	176	137	146	202	306	152%	2007
2 HICKORY	388	474	449	468	596	449	330	373	315	315	449	338	423	407	411	596	145%	2005
3 LIPAN	1180	2081	897	1090	1768	4580	3071	5799	723	3870	1388	2826	2959	2668	2,792	5,814	208%	1993
4 OTHER	1122	1730	859	811	1241	3129	2133	3920	536	2629	974	1926	2003	1814	1,064	3,920	368%	2008

COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 2]																	
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	AVG	MAX	% MAX is of AVG	YEAR OF MAX
5 UNKNOWN	-	-	-	-	-	-	-	44	75	106	268	2	0	-	83	268	325%	2011
GILLESPIE																		
1 EDWARDS-TRINITY-PLATEAU	379	377	361	375	488	800	654	822	786	1038	1185	732	686	680	320	1,185	371%	2011
2 ELLENBURGER-SAN SABA	3927	3822	3615	3667	3947	3495	3020	3464	3433	3380	4462	4075	4096	3275	3,594	5,124	143%	1985
3 HICKORY	593	593	587	623	544	696	241	659	644	536	974	651	705	696	372	974	262%	2011
4 MARBLE FALLS	-	-	-	-	-	10	8	9	9	9	10	10	9	8	9	10	110%	2006
5 OTHER	91	91	87	90	108	277	220	274	268	317	370	266	250	236	202	370	183%	2011
6 TRINITY	1768	1803	1871	1872	1745	1885	821	1793	1729	1589	2603	1838	1920	1861	2,023	3,723	184%	1996
7 UNKNOWN	-	-	-	-	-	-	-	1	1	1	1	-	-	-	1	1	100%	2008
GLASSCOCK																		
1 EDWARDS-TRINITY-PLATEAU	22466	22999	39065	38357	38337	40358	32832	37125	39695	49454	46112	39169	42927	44247	37,971	59,260	156%	1995
2 OGALLALA	3342	3422	5826	5732	5730	6052	4933	5565	5949	7411	6914	5864	6426	6614	4,428	9,735	220%	1995
3 OTHER	264	270	461	453	452	476	387	438	469	584	544	462	507	521	443	584	132%	2010
4 UNKNOWN	-	-	-	-	-	-	-	381	446	510	1251	3262	2485	3596	1,704	3,596	211%	2014
HOWARD																		
1 DOCKUM	224	210	162	202	207	280	484	391	528	534	779	533	422	457	289	779	270%	2011
2 EDWARDS-TRINITY-PLATEAU	1758	1731	1543	1666	7862	7815	2680	2175	2961	3075	4071	2742	2163	2395	1,880	7,862	418%	2005
3 OGALLALA	2341	2279	1715	1868	1968	3487	4024	5062	4422	5646	6748	4326	3719	4297	3,344	6,748	202%	2011
4 OTHER	229	214	165	199	205	242	452	357	488	487	728	484	371	416	358	728	203%	2011
5 UNKNOWN	-	-	-	-	-	-	-	80	196	312	478	797	844	1507	602	1,507	250%	2014
LAMPASAS																		
1 ELLENBURGER-SAN SABA	21	23	20	21	21	48	37	37	29	28	29	21	18	17	30	76	256%	2000
2 MARBLE FALLS	39	40	41	41	44	47	34	60	56	20	22	23	24	26	38	60	156%	2000
3 OTHER	36	38	37	42	43	47	34	100	127	44	47	43	45	57	77	181	235%	1991
4 TRINITY	487	539	515	520	536	520	399	483	447	388	406	361	297	362	745	1,244	167%	1999
5 UNKNOWN	-	-	-	-	-	-	-	73	76	79	61	-	-	-	72	79	109%	2010
LLANO																		
1 ELLENBURGER-SAN SABA	211	309	315	306	296	522	495	682	510	159	149	190	179	186	202	682	338%	2008
2 HICKORY	700	936	706	1056	641	990	631	389	355	360	725	1025	677	652	976	1,527	156%	1994
3 OTHER	1055	1077	1034	733	593	630	551	558	584	586	629	606	546	411	741	1,097	148%	2000
4 TRINITY	-	-	-	-	-	-	-	-	0	-	-	-	-	0	0	0		2009
5 UNKNOWN	-	-	-	-	-	-	-	0	0	0	0	-	-	-	0	0		2008
MASON																		
1 EDWARDS-TRINITY-PLATEAU	7	6	9	10	14	18	15	15	13	10	14	13	11	10	11	18	158%	2006
2 ELLENBURGER-SAN SABA	128	112	152	80	92	107	75	85	91	67	96	88	75	76	114	165	145%	1992
3 HICKORY	10107	10503	9845	10138	9283	8056	4318	6545	7768	4803	6857	6516	5926	6279	11,390	19,029	167%	1988
4 MARBLE FALLS	82	67	107	-	-	-	-	-	-	-	-	-	-	-	124	160	129%	1992
5 OGALLALA	-	-	-	89	95	-	-	-	-	-	-	-	-	-	92	95	103%	2005
6 OTHER	318	315	333	342	351	356	228	286	314	212	307	281	242	251	298	356	120%	2006
7 TRINITY	-	-	-	-	-	1	1	1	1	2	2	2	2	1	1	2	138%	2010
8 UNKNOWN	-	-	-	-	-	-	-	275	275	275	275	-	-	-	275	275	100%	2008
MCCULLOCH																		

COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 2]																	
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	AVG	MAX	% MAX is of AVG	YEAR OF MAX
1 EDWARDS-TRINITY-PLATEAU	12	15	11	3	4	4	4	4	7	11	9	80	46	44	21	80	382%	2012
2 ELLENBURGER-SAN SABA	285	341	283	269	291	268	265	257	320	492	290	246	214	216	307	492	160%	2010
3 HICKORY	5207	5038	6711	6454	6739	8428	7004	4994	5779	6529	7521	7117	6319	7560	6,339	8,428	133%	2006
4 MARBLE FALLS	35	39	52	45	45	43	30	17	51	46	42	36	31	33	29	52	180%	2003
5 OTHER	86	166	128	111	129	140	109	125	110	181	127	102	99	137	145	191	132%	1985
6 UNKNOWN	-	-	-	-	-	-	-	2631	2651	2672	2638	-	-	-	2,648	2,672	101%	2010
MENARD																		
1 EDWARDS-TRINITY-PLATEAU	770	728	663	595	630	1075	899	582	897	585	426	591	442	409	667	1,075	161%	2006
2 ELLENBURGER-SAN SABA	5	4	6	4	5	4	4	4	5	5	5	5	5	4	5	7	137%	1980
3 HICKORY	84	84	37	28	43	312	212	0	162	171	66	201	93	86	78	312	403%	2006
4 OTHER	236	234	119	87	125	798	548	16	431	455	195	530	260	225	240	798	332%	2006
5 TRINITY	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0		2006
6 UNKNOWN	-	-	-	-	-	-	-	2	106	210	569	1	-	-	178	569	320%	2011
MILLS																		
1 ELLENBURGER-SAN SABA	59	58	57	57	93	110	93	31	32	90	94	62	82	84	73	110	150%	2006
2 OTHER	146	119	131	56	62	38	32	35	35	34	37	35	32	27	144	349	243%	1996
3 TRINITY	460	536	475	762	907	671	636	678	975	2090	3821	3203	2327	1398	1,077	3,821	355%	2011
4 UNKNOWN	-	-	-	-	-	-	-	0	0	0	0	-	-	-	0	0		2008
MITCHELL																		
1 DOCKUM	4803	5585	6832	7459	7608	8904	10337	9484	12928	10907	11537	17446	15048	16816	6,157	17,446	283%	2012
2 OTHER	2	2	2	6	15	19	1074	23	21	113	346	230	17	21	62	1,074	1719%	2007
3 PECOS	0	0	0	0	1	2	2	2	2	2	2	2	1	1	1	2	176%	2006
4 UNKNOWN	-	-	-	-	-	-	-	278	254	229	180	138	158	53	184	278	151%	2008
NOLAN																		
1 DOCKUM	2177	2195	2391	4352	5629	5483	6012	10324	11433	8300	12508	12825	12824	12000	4,555	12,825	282%	2012
2 EDWARDS-TRINITY-PLATEAU	2668	3020	3501	2577	2501	3420	3244	3308	2602	2134	2553	2282	2243	2209	1,649	3,501	212%	2003
3 OGALLALA	-	-	-	-	-	6	5	5	6	7	8	7	2	2	5	8	150%	2011
4 OTHER	929	974	1072	79	101	92	78	83	85	86	88	91	70	66	440	1,583	360%	2000
5 UNKNOWN	-	-	-	-	-	-	-	95	76	59	117	27	55	28	65	117	179%	2011
RUNNELS																		
1 EDWARDS-TRINITY-PLATEAU	4	4	3	3	15	19	17	20	19	21	22	15	14	13	13	22	171%	2011
2 LIPAN	240	100	98	7	30	34	32	37	36	39	41	27	34	32	62	240	385%	2001
3 OTHER	1050	2054	1709	1687	2141	3167	1909	3279	2720	2828	2196	3911	3439	2978	2,422	4,639	192%	1991
4 UNKNOWN	-	-	-	-	-	-	-	54	60	66	152	3	0	-	56	152	272%	2011
SAN SABA																		
1 ELLENBURGER-SAN SABA	432	436	548	1349	566	570	796	368	1252	839	1332	1457	1184	1504	625	1,504	241%	2014
2 HICKORY	648	627	908	5976	999	856	1361	405	2353	1233	2333	2670	2148	2890	1,482	5,976	403%	2004
3 MARBLE FALLS	1420	1319	1265	452	1078	1080	855	1100	1076	39	81	391	88	21	853	1,458	171%	2000
4 OTHER	75	76	80	98	61	84	104	65	145	110	148	156	120	141	103	156	151%	2012
5 UNKNOWN	-	-	-	-	-	-	-	382	391	400	382	11	-	-	313	400	128%	2010
SCHLEICHER																		
1 EDWARDS-TRINITY-PLATEAU	2137	2151	1665	1484	1730	2009	1509	2172	2508	2480	3161	3036	2657	2997	2,495	4,300	172%	1999

COUNTY/AQUIFER	REPORTED GROUNDWATER USE (units are acre-feet per year) [part 2]																	
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	AVG	MAX	% MAX is of AVG	YEAR OF MAX
2 OTHER	-	-	-	-	-	1	0	0	1	1	1	1	1	0	1	1	150%	2006
3 UNKNOWN	-	-	-	-	-	-	-	44	58	72	160	105	171	91	100	171	171%	2013
SCURRY																		
1 DOCKUM	2716	3659	2999	3505	4332	6739	5486	4757	8382	6806	7908	10114	7754	7977	5,376	10,114	188%	2012
2 OTHER	140	174	229	212	228	29	26	28	28	30	30	28	24	20	225	1,081	481%	1980
3 UNKNOWN	-	-	-	-	-	-	-	89	90	92	17	14	38	54	56	92	163%	2010
STERLING																		
1 DOCKUM	11	9	6	6	7	9	9	8	8	7	7	7	7	7	8	11	142%	2001
2 EDWARDS-TRINITY-PLATEAU	526	505	376	352	379	458	428	487	605	456	556	489	581	535	729	1,229	169%	1992
3 OTHER	728	743	628	545	512	612	484	660	800	416	575	501	615	550	760	1,383	182%	1985
4 PECOS	70	71	56	48	47	61	52	70	95	67	89	78	95	85	70	95	136%	2009
5 UNKNOWN	-	-	-	-	-	-	-	76	106	136	84	206	256	252	159	256	161%	2013
TAYLOR																		
1 EDWARDS-TRINITY-PLATEAU	106	101	94	97	151	191	152	203	308	393	378	349	223	90	143	393	275%	2010
2 OTHER	645	566	373	372	1401	1342	848	315	802	1599	2507	1444	1420	208	1,344	4,298	320%	1999
3 SEYMOUR	11	8	3	3	32	43	30	12	27	57	85	52	49	10	29	85	296%	2011
4 TRINITY	64	62	60	59	77	83	66	95	150	189	173	168	103	39	97	189	194%	2010
5 UNKNOWN	-	-	-	-	-	-	-	163	170	177	175	-	1	-	137	177	129%	2010
TOM GREEN																		
1 BLAINE	2	2	2	2	15	19	14	18	24	31	34	29	23	21	16	34	214%	2011
2 EDWARDS-TRINITY-PLATEAU	371	420	383	728	1553	1781	2244	2939	2686	2235	1863	2585	1800	1911	1,136	2,939	259%	2008
3 LIPAN	24604	26093	23893	15667	17857	20850	41787	51918	41026	24333	7229	33142	22150	26844	28,415	71,143	250%	1995
4 OTHER	3526	3725	3423	9803	11349	13472	27340	34120	27021	16480	5066	22406	15012	17848	10,781	34,120	316%	2008
5 UNKNOWN	-	-	-	-	-	-	-	459	476	494	464	-	1	-	379	494	130%	2010
TRAVIS																		
1 EDWARDS-BFZ	12782	12064	13280	13160	15048	13507	6884	10517	9900	7262	10091	7785	8245	8521	8,116	15,048	185%	2005
2 OTHER	1472	1552	1473	1582	1943	2549	2135	2499	2911	3096	5146	3602	2551	1631	1,874	5,146	275%	2011
3 TRINITY	1969	1944	1944	1754	1929	3591	2838	3461	4594	8801	10364	7636	8808	6241	3,342	10,364	310%	2011
4 UNKNOWN	-	-	-	-	-	-	-	1118	1178	1239	1025	-	-	-	1,140	1,239	109%	2010

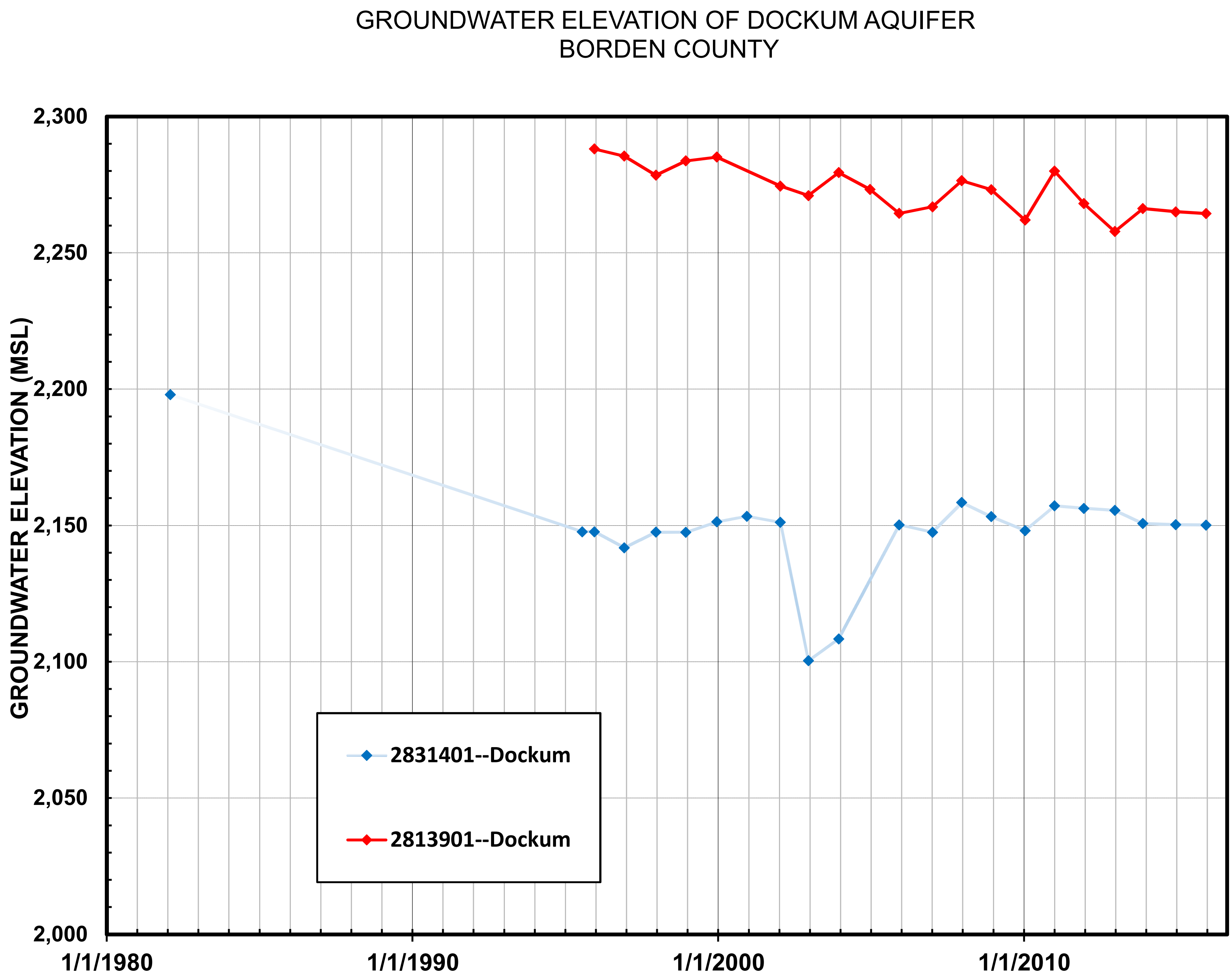
Yellow Shade Represents Year of Maximum Use

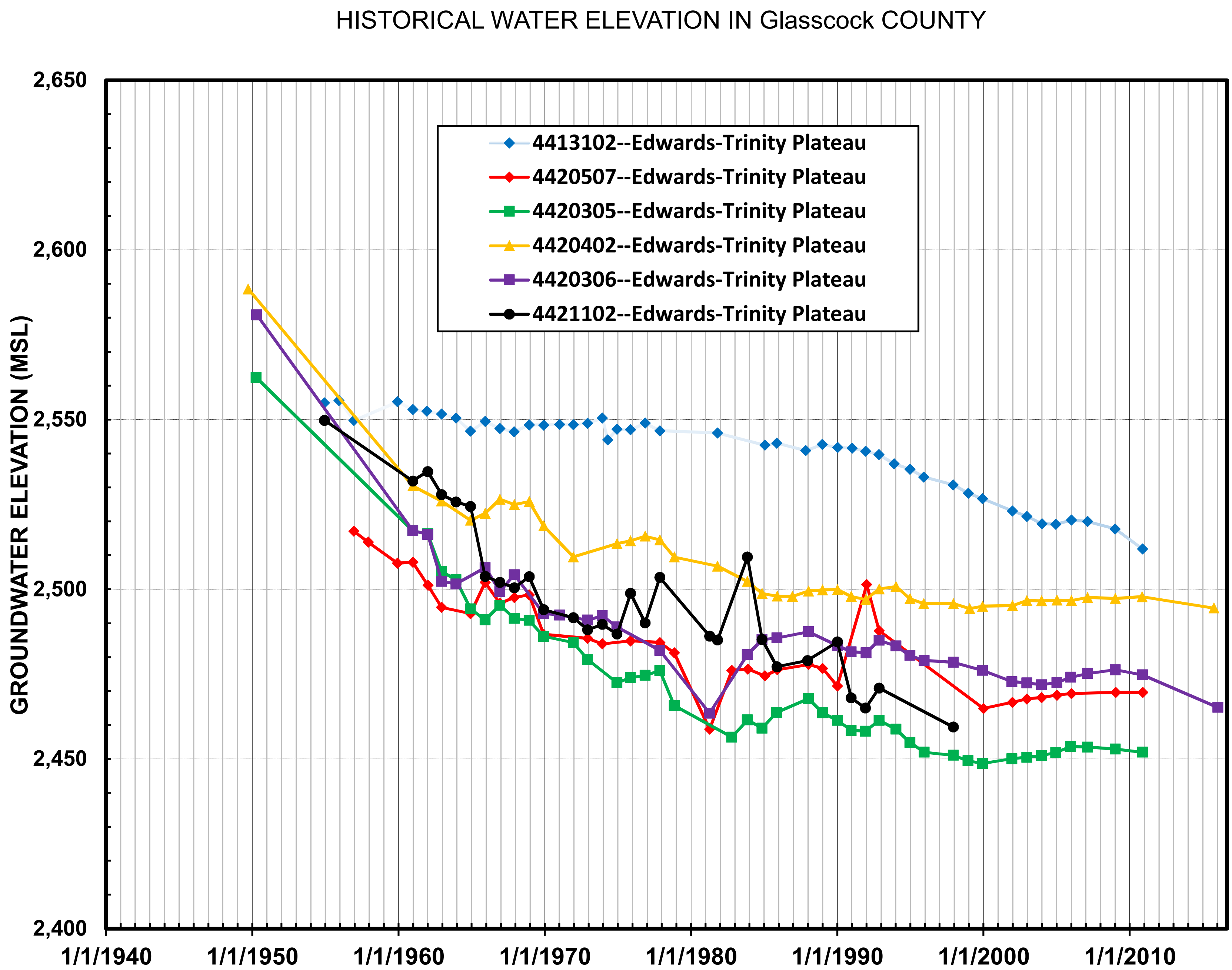
GROUNDWATER USE AND MONITOR WELL INFORMATION BY COUNTY

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			GROUNDWATER USE (1980-2014)			MONITOR WELL DATA	
COUNTY	ASSOC. STUDY SITES	AQUIFER NAME	ANNUAL AVERAGE (acre-feet/year)	ANNUAL MAXIMUM (acre-feet/year)	YEAR OF MAXIMUM	NUMBER OF WELLS PER AQUIFER WITH 5 OR MORE OBSERVATIONS	GENERAL OBS. (DECLINING; STEADY; MIXED; RISING)
BLANCO	10	Ellenburger-San Saba	921	1,565	2012	8	MIXED
		Hickory	117	349	2012	4	STEADY
		Trinity	686	2,109	2014	23	STEADY
BORDEN	11	Ogallala	1,944	8,254	1997	9	RISING
		Dockum	26	50	2006	2	DECLINING
BROWN	8, 14	Trinity	1,625	3,799	1999	21	MIXED
COKE	12, 13	Edwards-Trinity-Plateau	75	189	2011	5	RISING
		Other	811	1,509	1998	17	MIXED
COLEMAN	8, 14	Other	87	167	1985	7	MIXED
CONCHO	3,5	Edwards-Trinity-Plateau	202	306	2007	16	RISING
		Hickory	411	596	2005	1	DECLINING
		Lipan	2,792	5,814	1993	5	MIXED
		Other	1,064	3,920	2008	24	MIXED
GILLESPIE	10	Edwards-Trinity-Plateau	320	1,185	2011	17	MIXED
		Ellenburger-San Saba	3,594	5,124	1985	47	DECLINING
		Hickory	372	974	2011	24	DECLINING
		Marble Falls	9	10	2006	2	RISING
		Other	202	370	2011	8	DECLINING
		Trinity	2,023	3,723	1996	48	DECLINING
GLASSCOCK	1	Edwards-Trinity-Plateau	37,971	59,260	1995	61	DECLINING
		Ogallala	4,428	9,735	1995	19	STEADY
		Other	443	584	2010	5	STEADY
HOWARD	11, 12	Dockum	289	779	2011	4	STEADY
		Edwards-Trinity-Plateau	1,880	7,862	2005	3	STEADY
		Ogallala	3,344	6,748	2011	47	STEADY
		Other	358	728	2011	2	STEADY
LLANO	9	Ellenburger-San Saba	202	682	2008	1	DECLINING
		Hickory	976	1,527	1994	7	STEADY
		Other	741	1,097	2000	12	STEADY
NOLAN	13	Dockum	4,555	12,825	2012	18	MIXED
		Edwards-Trinity-Plateau	1,649	3,501	2003	12	STEADY
		Other	440	1,583	2000	3	STEADY
MASON	6,9	Ellenburger-San Saba	114	165	1992	2	DECLINING
		Hickory	11,390	19,029	1988	90	MIXED
		Other	298	356	2006	7	STEADY
MCCULLOCH	5,6	Edwards-Trinity-Plateau	21	80	2012	7	STEADY
		Ellenburger-San Saba	307	492	2010	8	DECLINING
		Hickory	6,339	8,428	2006	110	DECLINING
		Other	145	191	1985	6	DECLINING
MENARD	4,5	Edwards-Trinity-Plateau	667	1,075	2006	22	STEADY
		Ellenburger-San Saba	5	7	1980	2	DECLINING
		Hickory	78	312	2006	3	DECLINING
		Other	240	798	2006	4	MIXED
MILLS	8, 14	Trinity	1,077	3,821	2011	14	MIXED
MITCHELL	11, 12	Dockum	6,157	17,446	2012	58	MIXED
		Other	62	1,074	2007	3	MIXED
RUNNELS	3,7, 13	Lipan	62	240	2001	9	MIXED
		Other	2,422	4,639	1991	47	MIXED

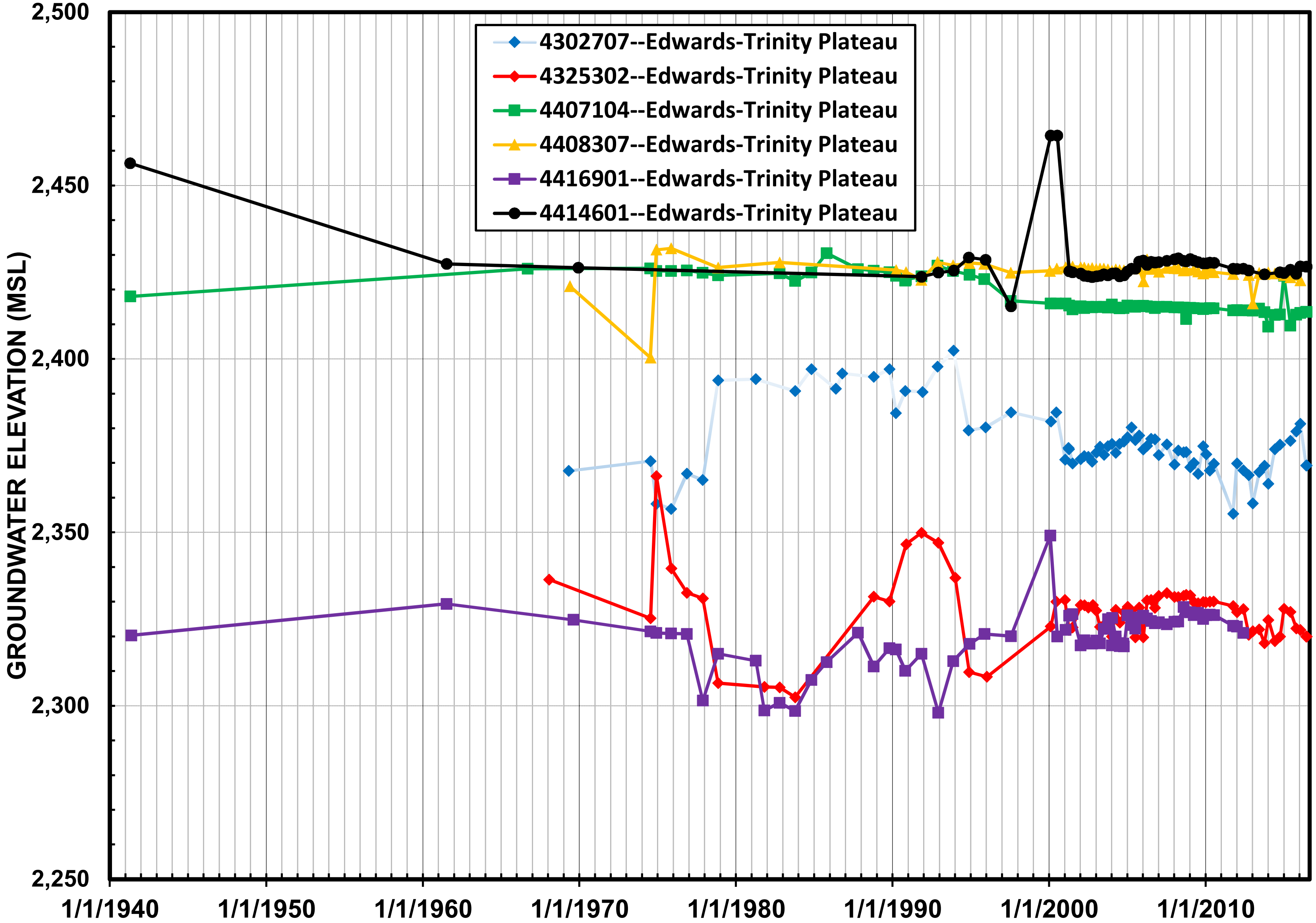
GROUNDWATER USE AND MONITOR WELL INFORMATION BY COUNTY

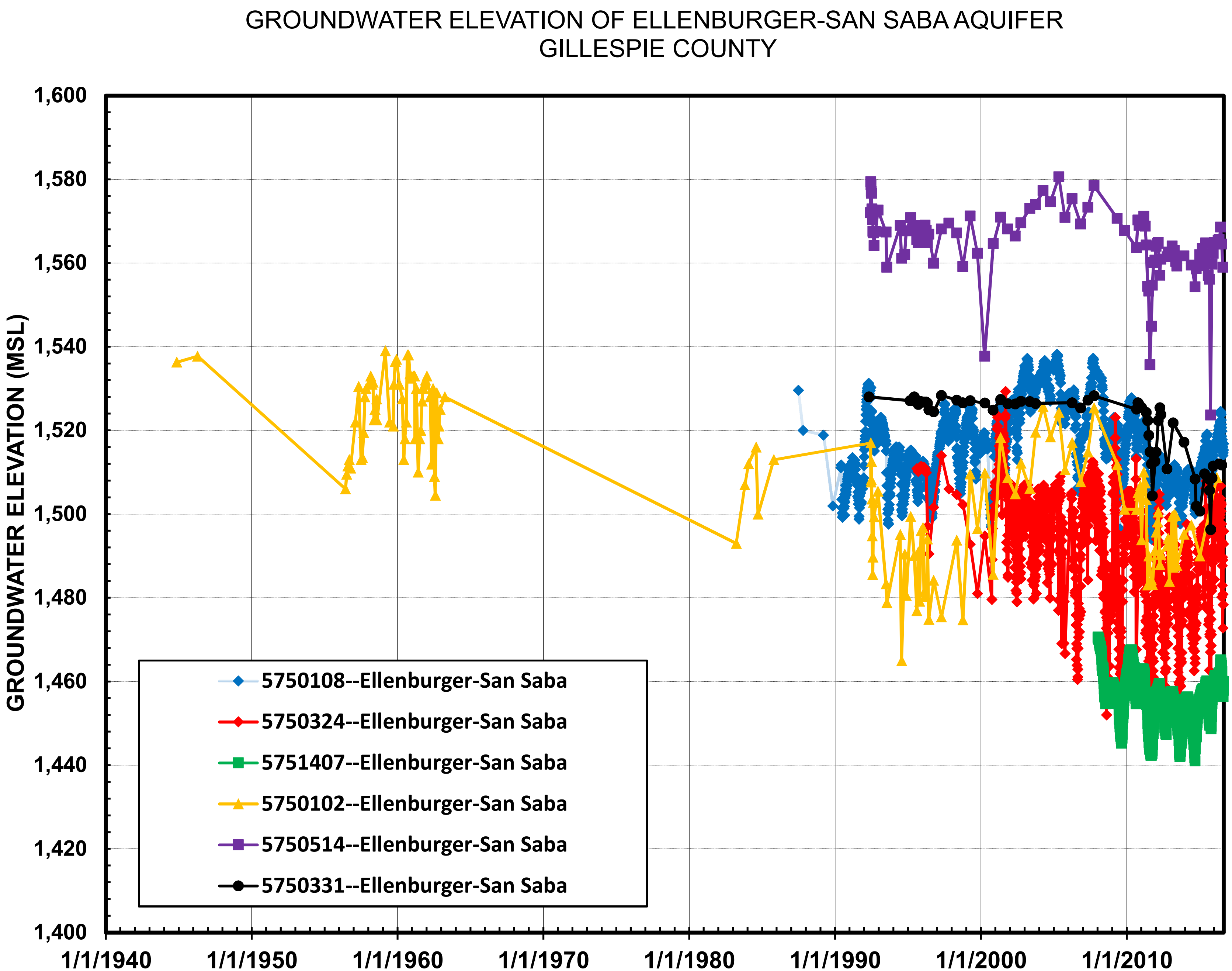
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			GROUNDWATER USE (1980-2014)			MONITOR WELL DATA	
COUNTY	ASSOC. STUDY SITES	AQUIFER NAME	ANNUAL AVERAGE (acre-feet/year)	ANNUAL MAXIMUM (acre-feet/year)	YEAR OF MAXIMUM	NUMBER OF WELLS PER AQUIFER WITH 5 OR MORE OBSERVATIONS	GENERAL OBS. (DECLINING; STEADY; MIXED; RISING)
SAN SABA	6, 14	Ellenburger-San Saba	625	1,504	2014	12	MIXED
		Hickory	1,482	5,976	2004	34	DECLINING
		Marble Falls	853	1,458	2000	6	STEADY
		Other	103	156	2012	6	MIXED
SCHLEICHER	2,4	Edwards-Trinity-Plateau	2,495	4,300	1999	56	MIXED
SCURRY	11	Dockum	5,376	10,114	2012	36	RISING
		Ogallala	NA	NA	NA	1	RISING
		Other	225	1,081	1980	2	RISING
STERLING	1, 12	Dockum	8	11	2001	1	RISING
		Edwards-Trinity-Plateau	729	1,229	1992	10	DECLINING
		Other	760	1,383	1985	6	DECLINING
TAYLOR	7	Edwards-Trinity-Plateau	143	393	2010	6	STEADY
		Other	1,344	4,298	1999	6	STEADY
		Seymour	29	85	2011	2	MIXED
		Trinity	97	189	2010	3	MIXED
TOM GREEN	1,2,3	Edwards-Trinity-Plateau	1,136	2,939	2008	13	RISING
		Lipan	28,415	71,143	1995	162	MIXED

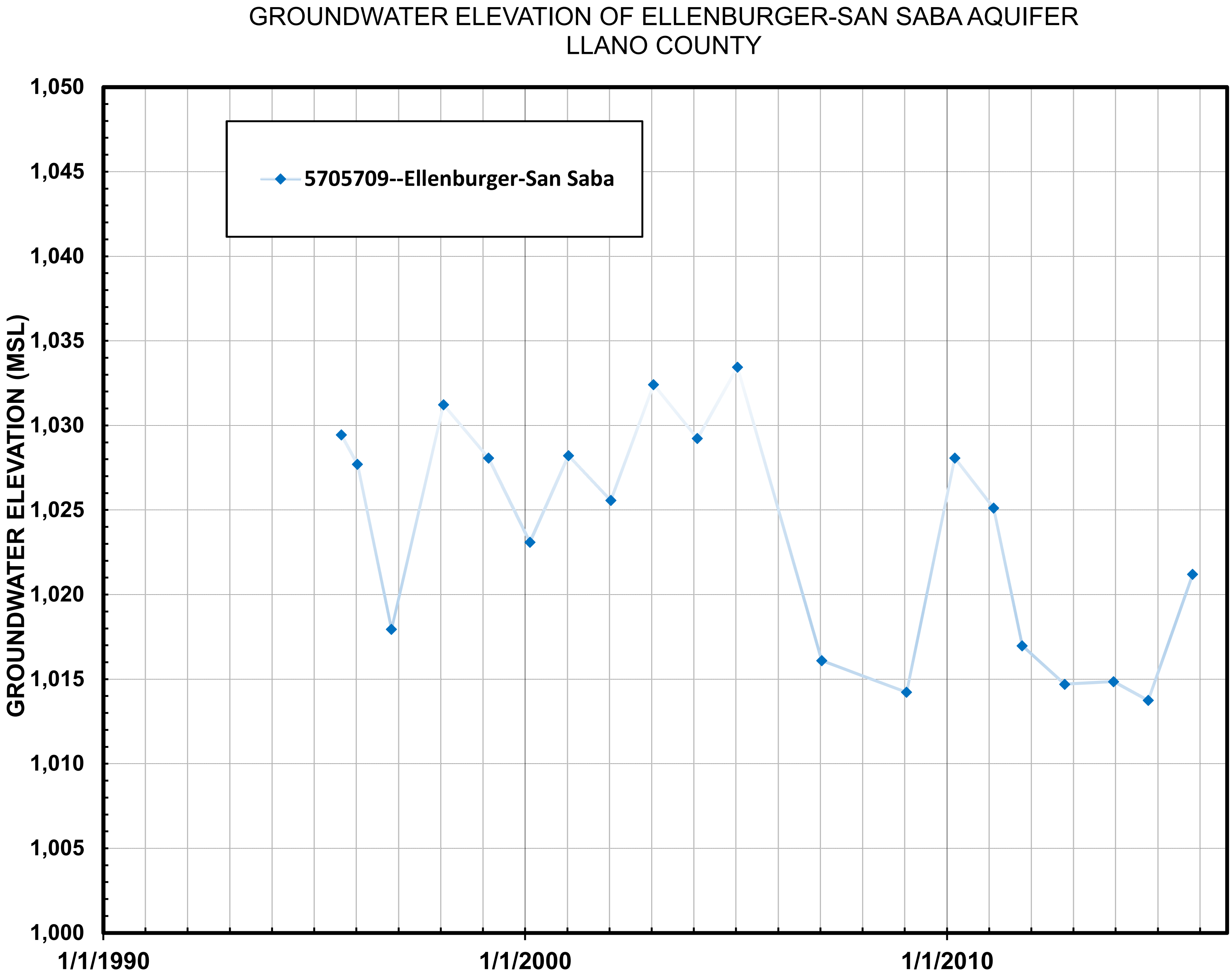

GROUNDWATER ELEVATION OF DOCKUM AQUIFER
BORDEN COUNTY
GROUNDWATER ELEVATION (MSL)
2,300
2,250
2,200
2,150
2,100
2,050
2,000
1/1/1980
1/1/1990
1/1/2000
1/1/2010
2831401--Dockum
2813901--Dockum

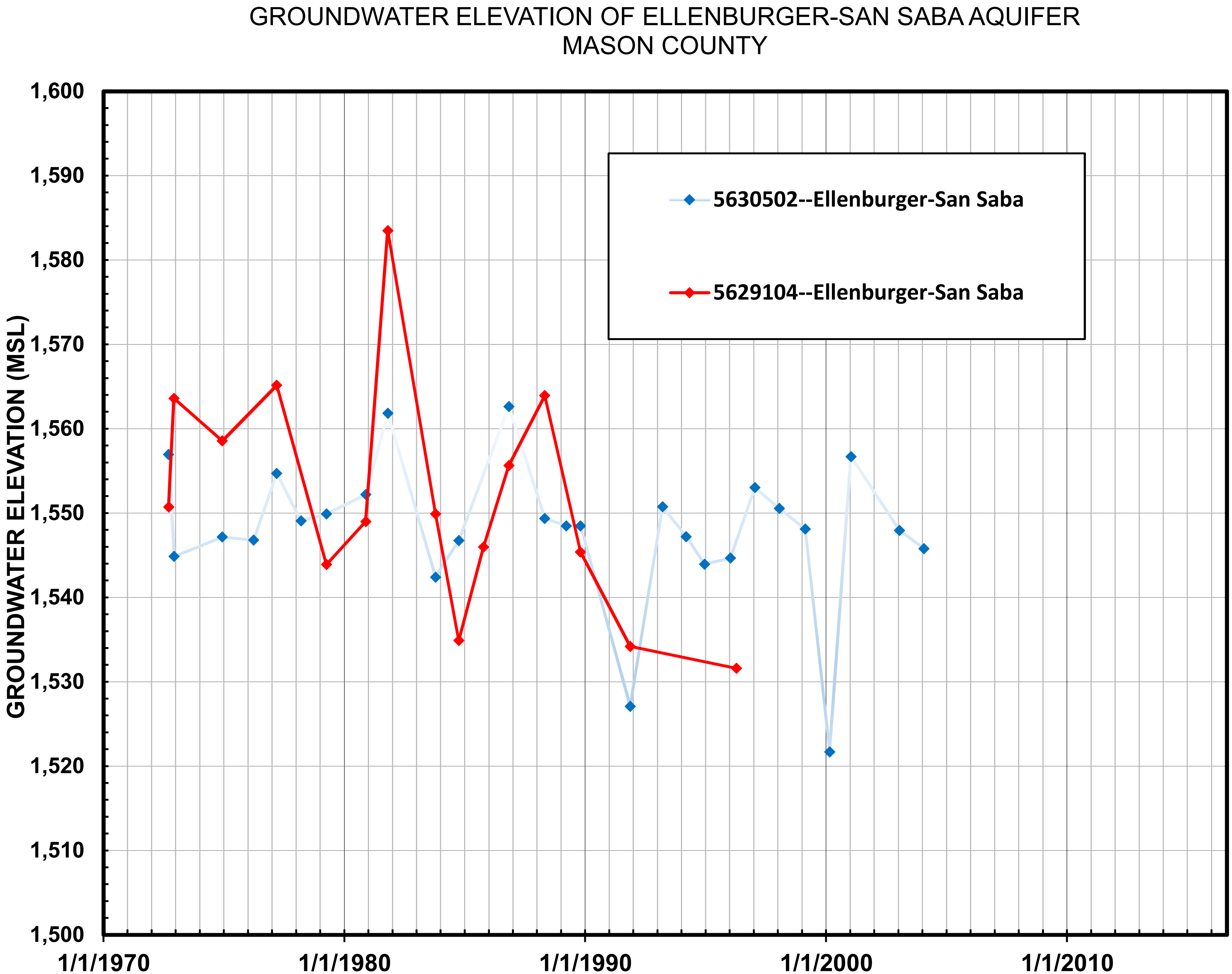

HISTORICAL WATER ELEVATION IN Glasscock COUNTY
GROUNDWATER ELEVATION (MSL)
2,650
2,600
2,550
2,500
2,450
2,400
1/1/1940
1/1/1950
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
4413102--Edwards-Trinity Plateau
4420507--Edwards-Trinity Plateau
4420305--Edwards-Trinity Plateau
4420402--Edwards-Trinity Plateau
4420306--Edwards-Trinity Plateau
4421102--Edwards-Trinity Plateau

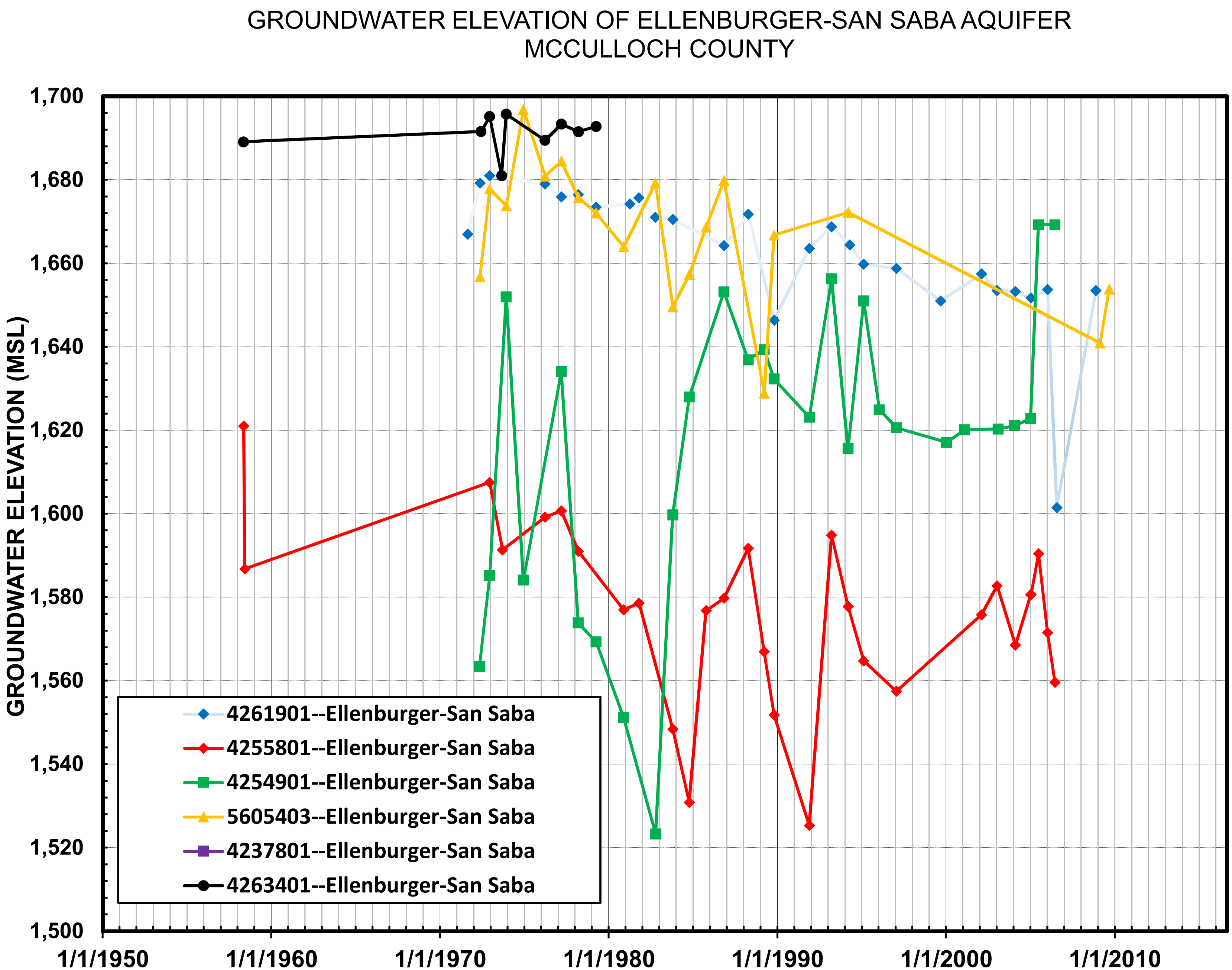
GROUNDWATER ELEVATION OF EDWARDS-TRINITY-PLATEAU AQUIFER
STERLING COUNTY

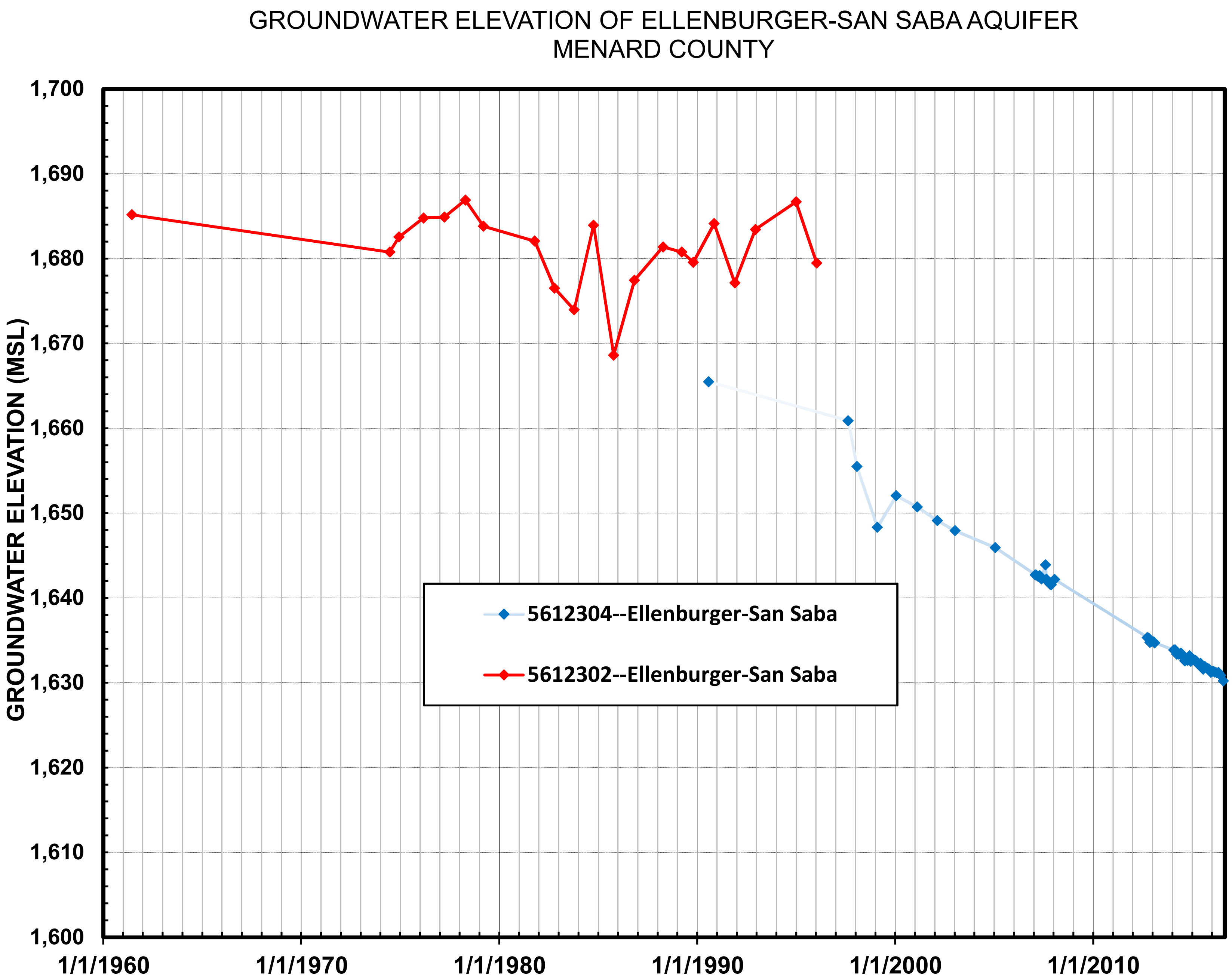


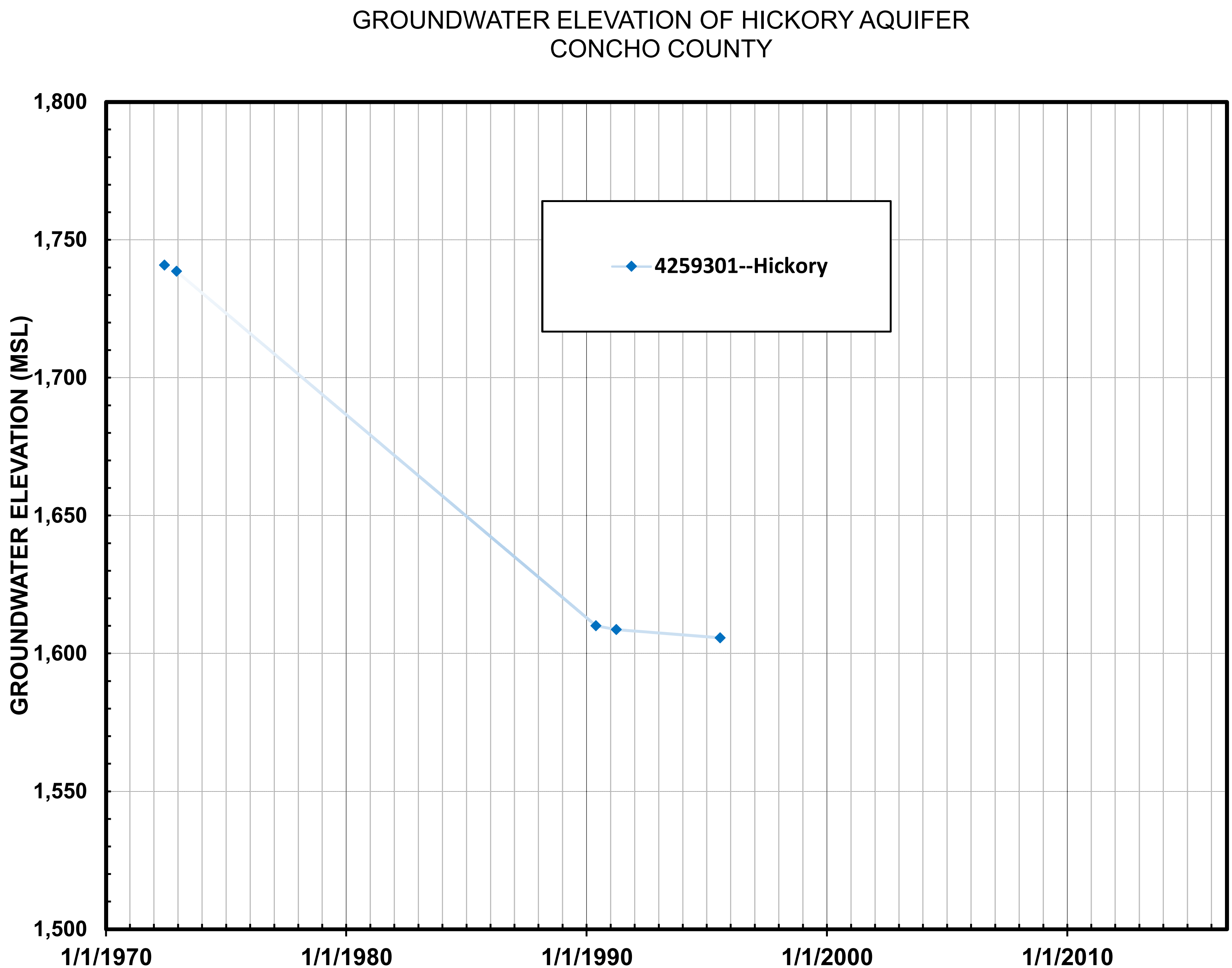

GROUNDWATER ELEVATION OF ELLENBURGER-SAN SABA AQUIFER
GILLESPIE COUNTY
GROUNDWATER ELEVATION (MSL)
1,600
1,580
1,560
1,540
1,520
1,500
1,480
1,460
1,440
1,420
1,400
1/1/1940
1/1/1950
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5750108--Ellenburger-San Saba
5750324--Ellenburger-San Saba
5751407--Ellenburger-San Saba
5750102--Ellenburger-San Saba
5750514--Ellenburger-San Saba
5750331--Ellenburger-San Saba

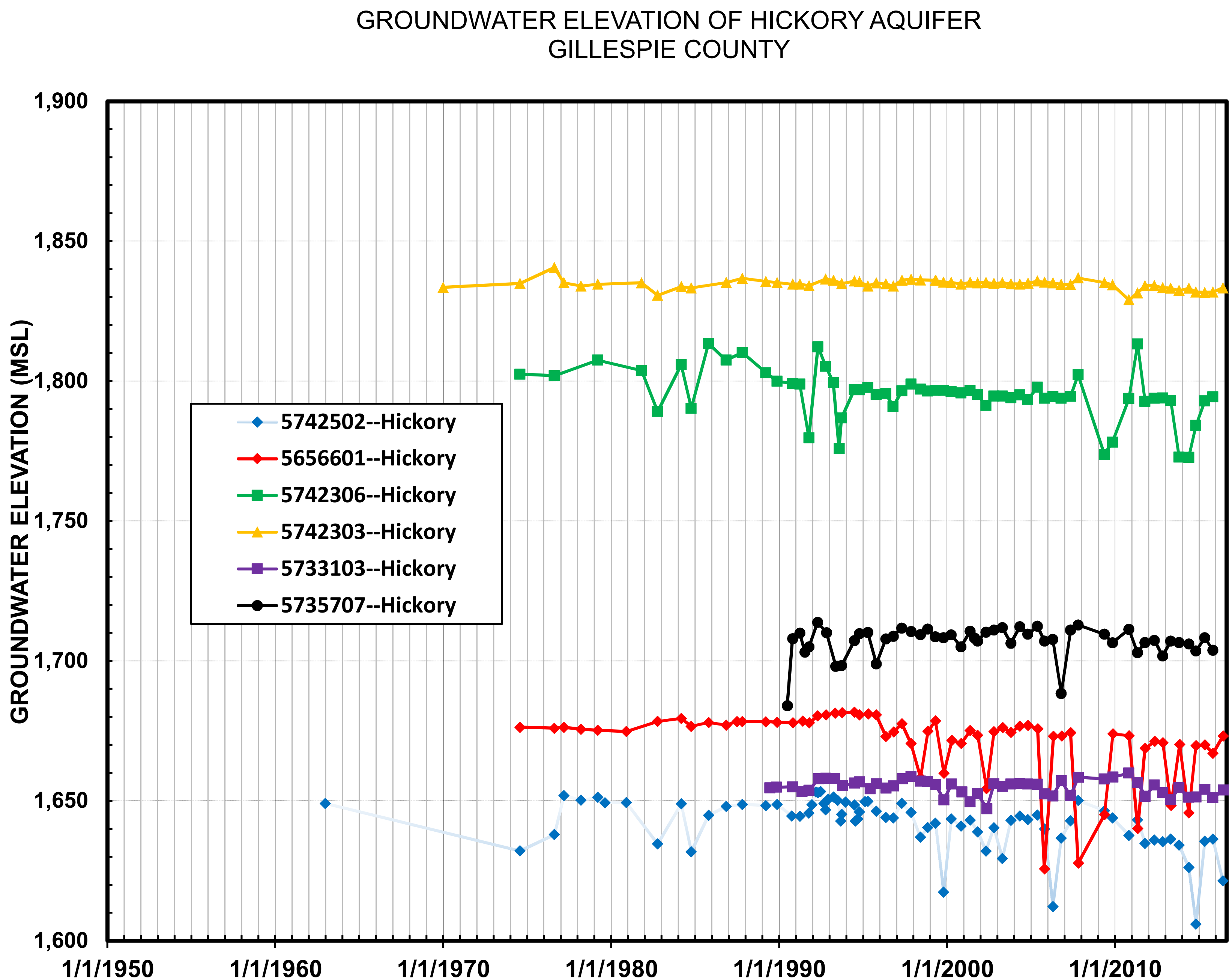

GROUNDWATER ELEVATION OF ELLENBURGER-SAN SABA AQUIFER
LLANO COUNTY
5705709--Ellenburger-San Saba
GROUNDWATER ELEVATION (MSL)
1,050
1,045
1,040
1,035
1,030
1,025
1,020
1,015
1,010
1,005
1,000
1/1/1990
1/1/2000
1/1/2010

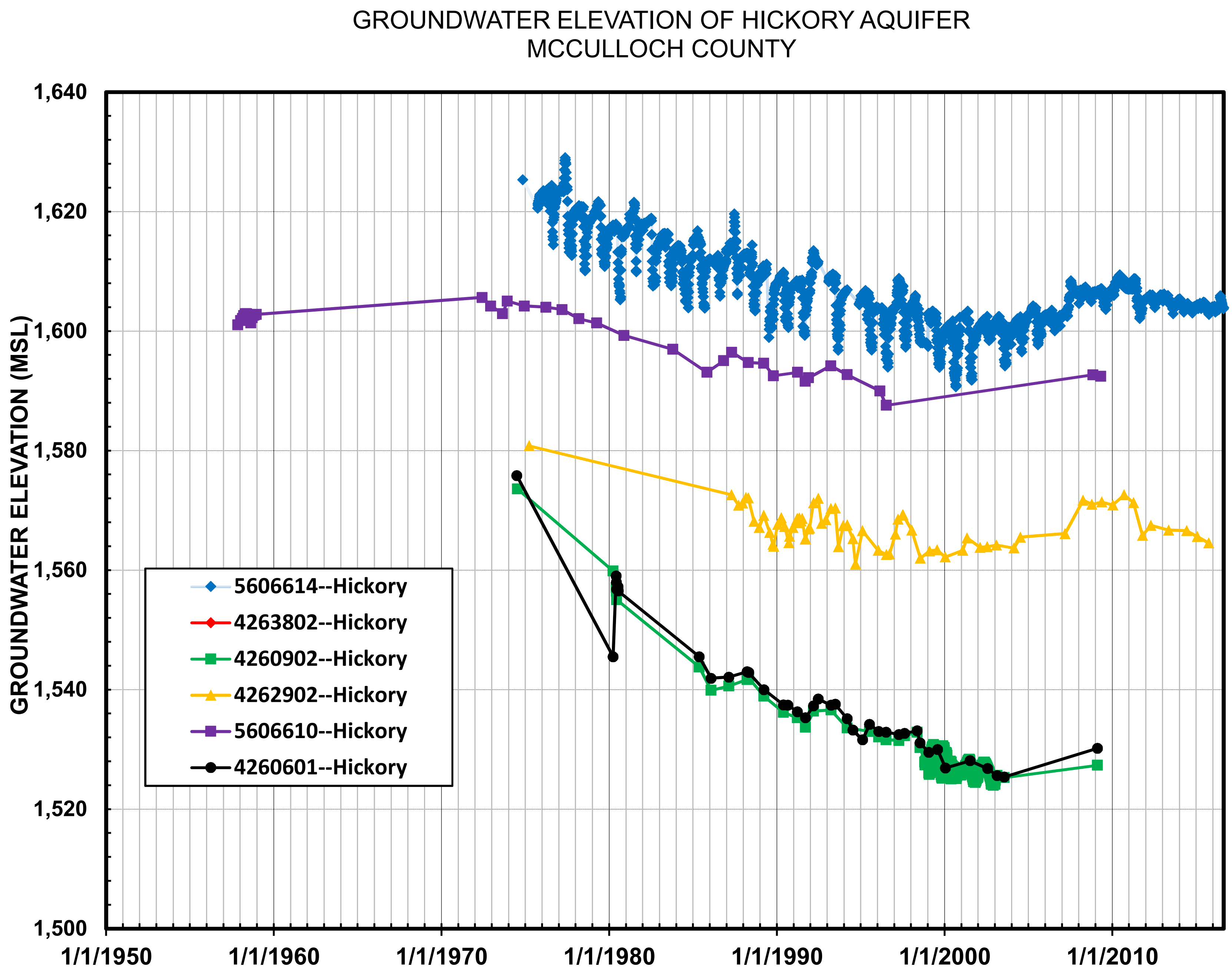

GROUNDWATER ELEVATION OF ELLENBURGER-SAN SABA AQUIFER
MASON COUNTY
GROUNDWATER ELEVATION (MSL)
1,600
1,590
1,580
1,570
1,560
1,550
1,540
1,530
1,520
1,510
1,500
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5630502--Ellenburger-San Saba
5629104--Ellenburger-San Saba

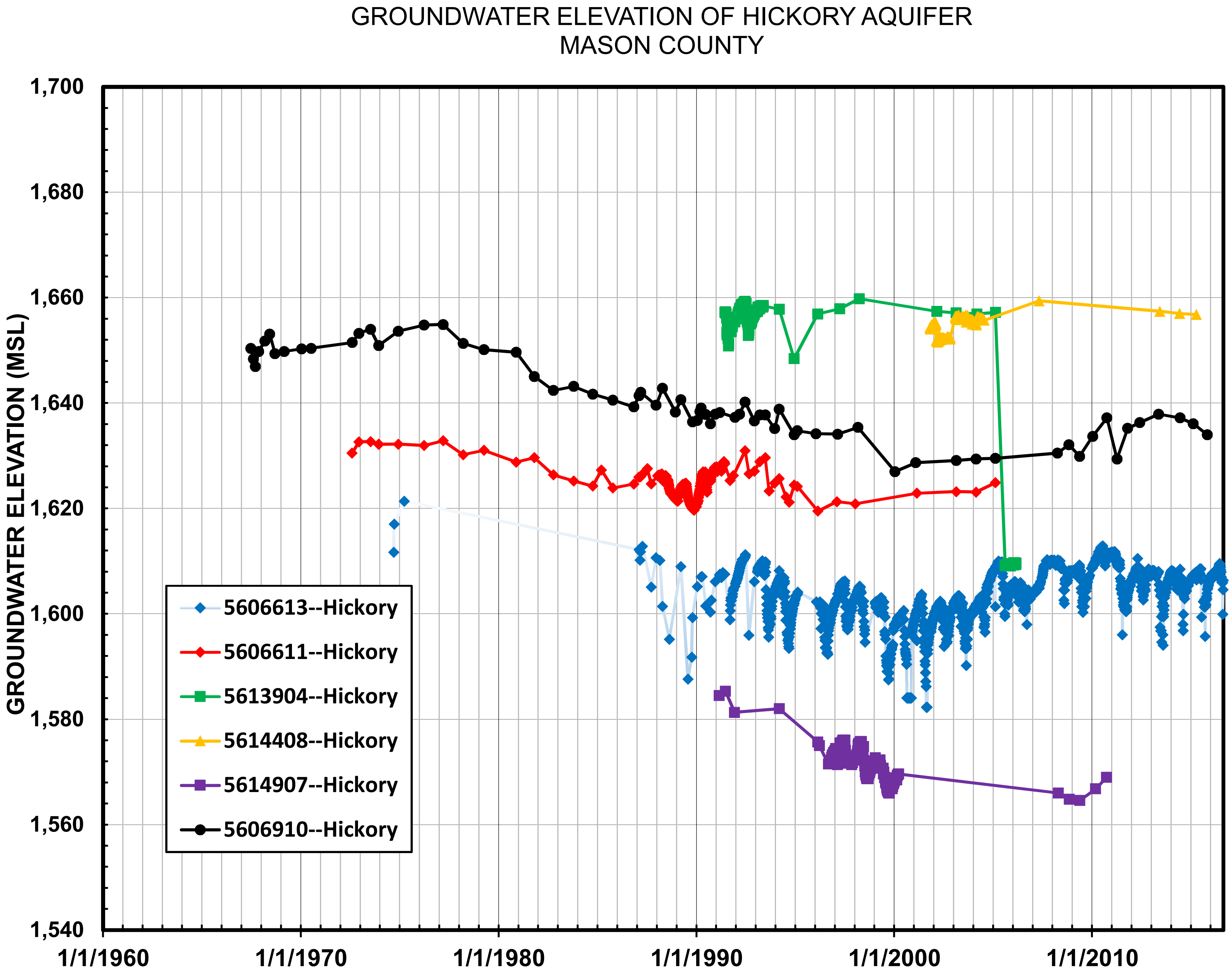

GROUNDWATER ELEVATION OF ELLENBURGER-SAN SABA AQUIFER
MCCULLOCH COUNTY
GROUNDWATER ELEVATION (MSL)
1,700
1,680
1,660
1,640
1,620
1,600
1,580
1,560
1,540
1,520
1,500
1/1/1950
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
4261901--Ellenburger-San Saba
4255801--Ellenburger-San Saba
4254901--Ellenburger-San Saba
5605403--Ellenburger-San Saba
4237801--Ellenburger-San Saba
4263401--Ellenburger-San Saba

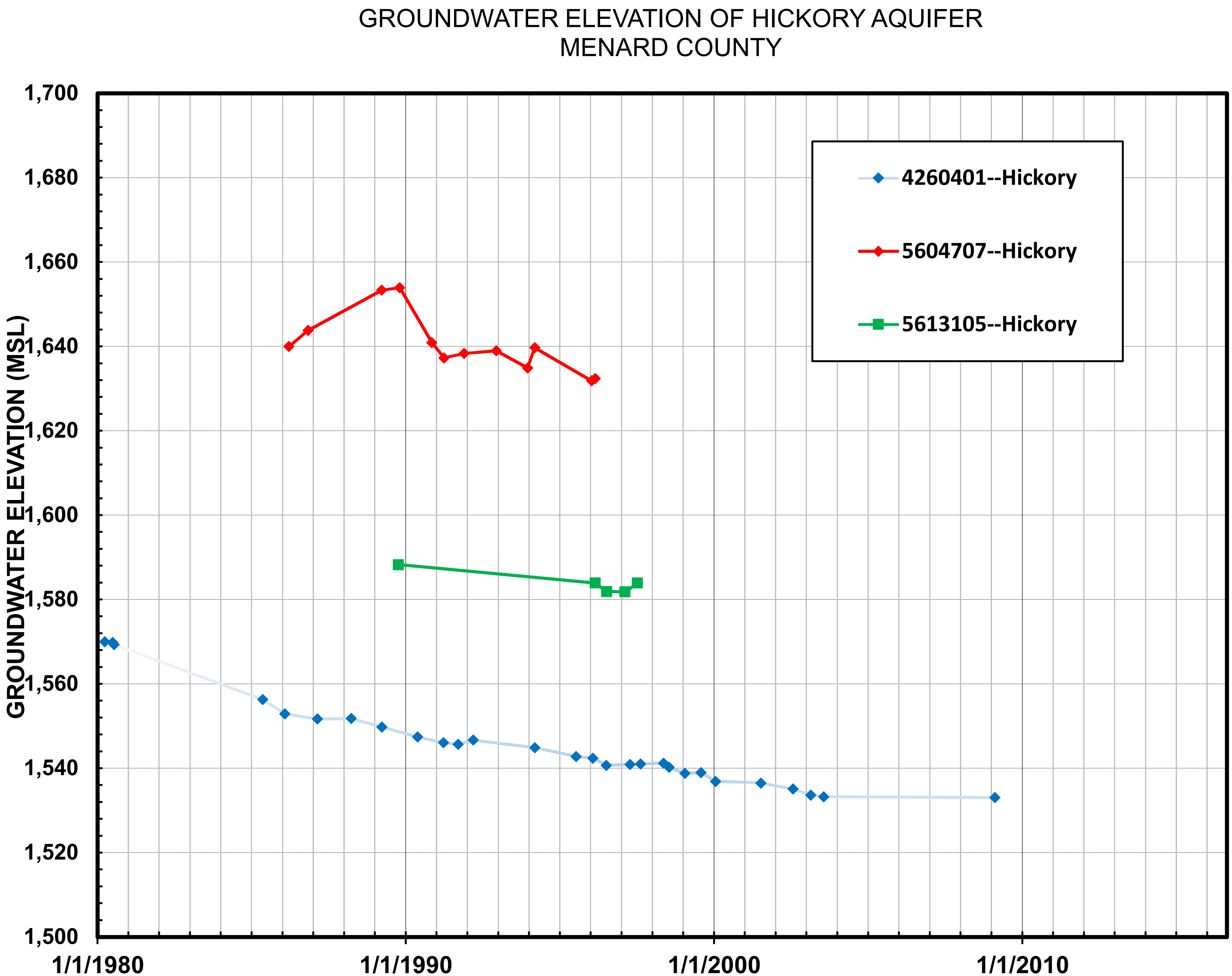

GROUNDWATER ELEVATION OF ELLENBURGER-SAN SABA AQUIFER
MENARD COUNTY
GROUNDWATER ELEVATION (MSL)
1,700
1,690
1,680
1,670
1,660
1,650
1,640
1,630
1,620
1,610
1,600
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5612304--Ellenburger-San Saba
5612302--Ellenburger-San Saba

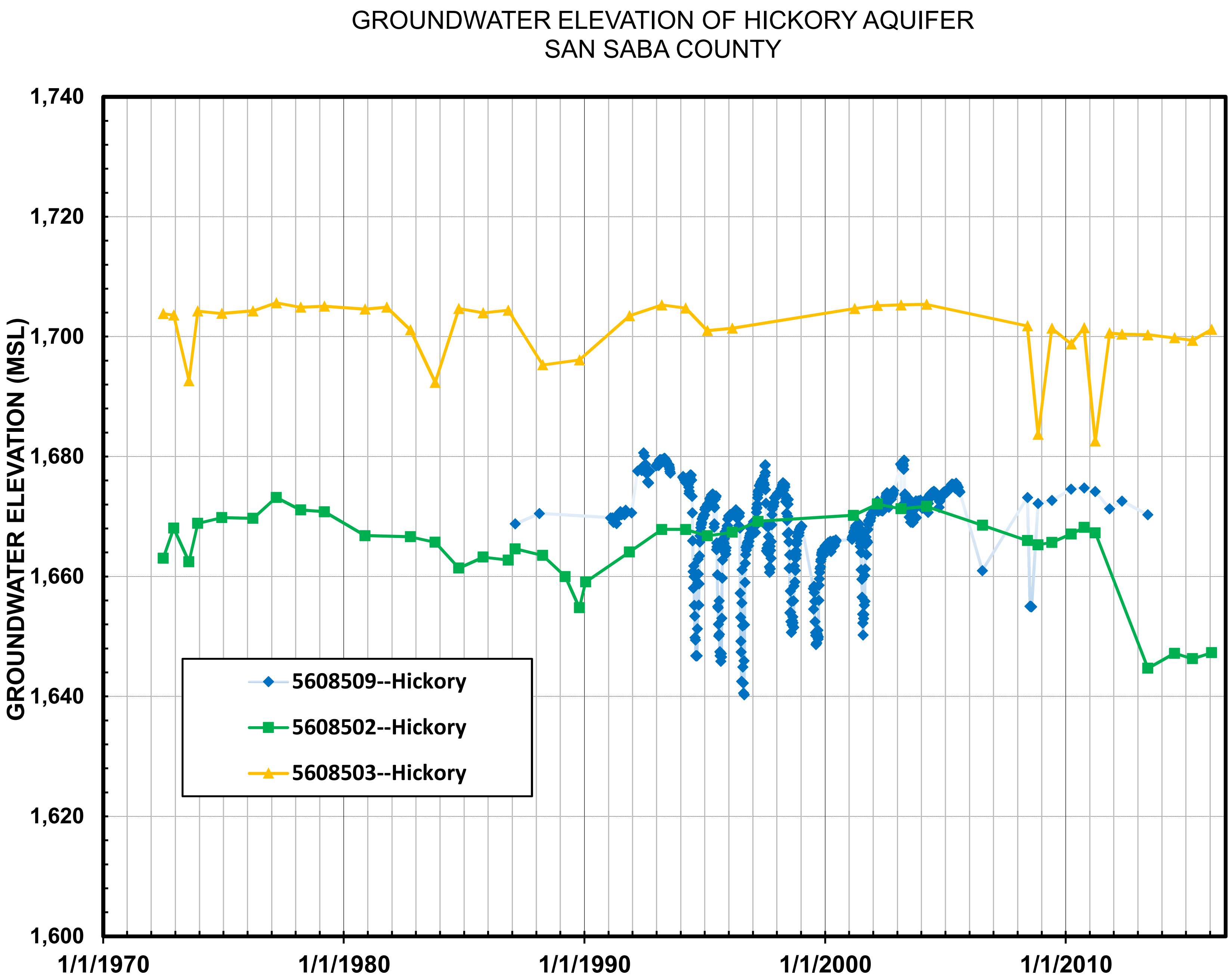

GROUNDWATER ELEVATION OF HICKORY AQUIFER
CONCHO COUNTY
GROUNDWATER ELEVATION (MSL)
1,800
1,750
1,700
1,650
1,600
1,550
1,500
4259301--Hickory
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010

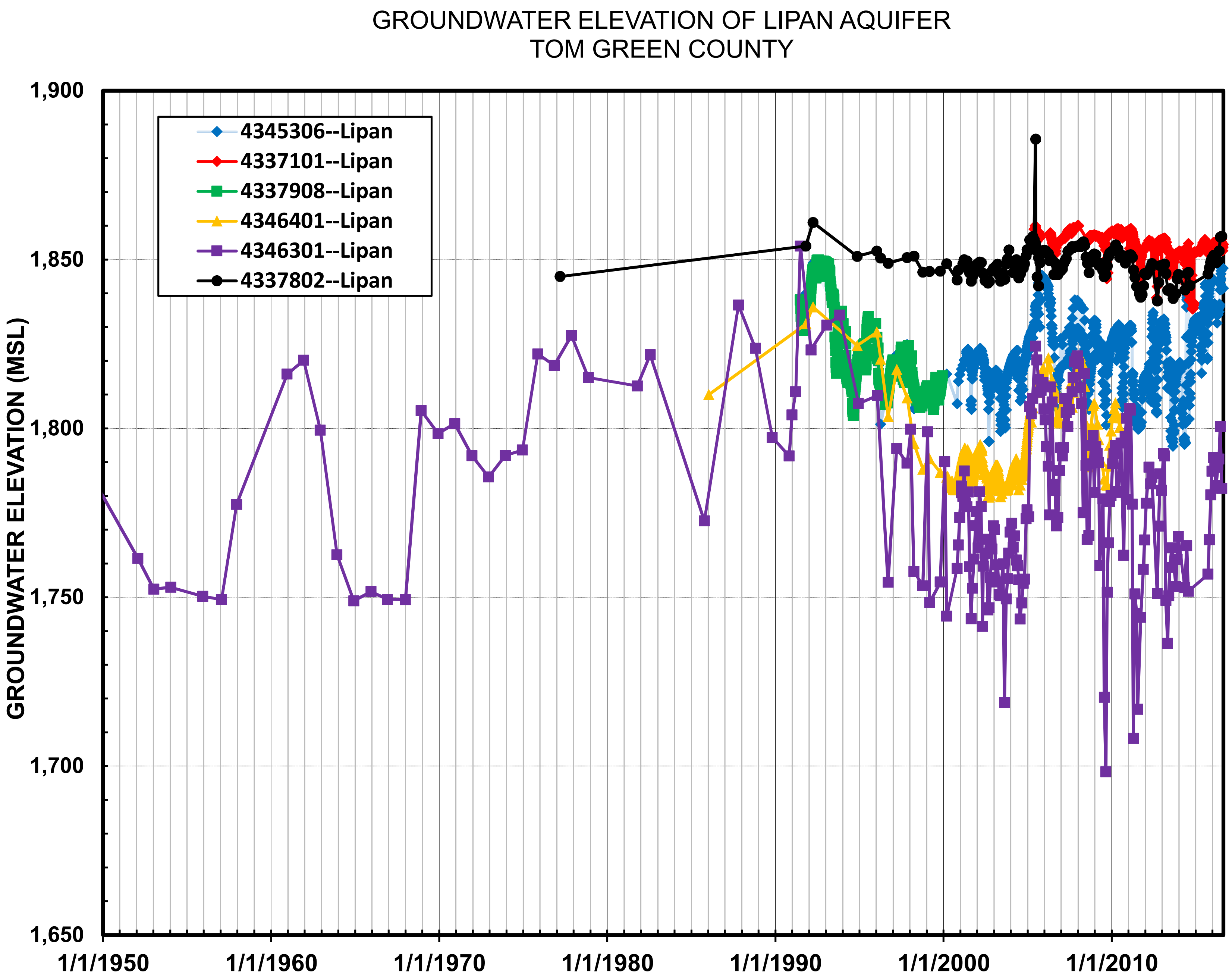

GROUNDWATER ELEVATION OF HICKORY AQUIFER
GILLESPIE COUNTY
GROUNDWATER ELEVATION (MSL)
1,900
1,850
1,800
1,750
1,700
1,650
1,600
1/1/1950
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5742502--Hickory
5656601--Hickory
5742306--Hickory
5742303--Hickory
5733103--Hickory
5735707--Hickory

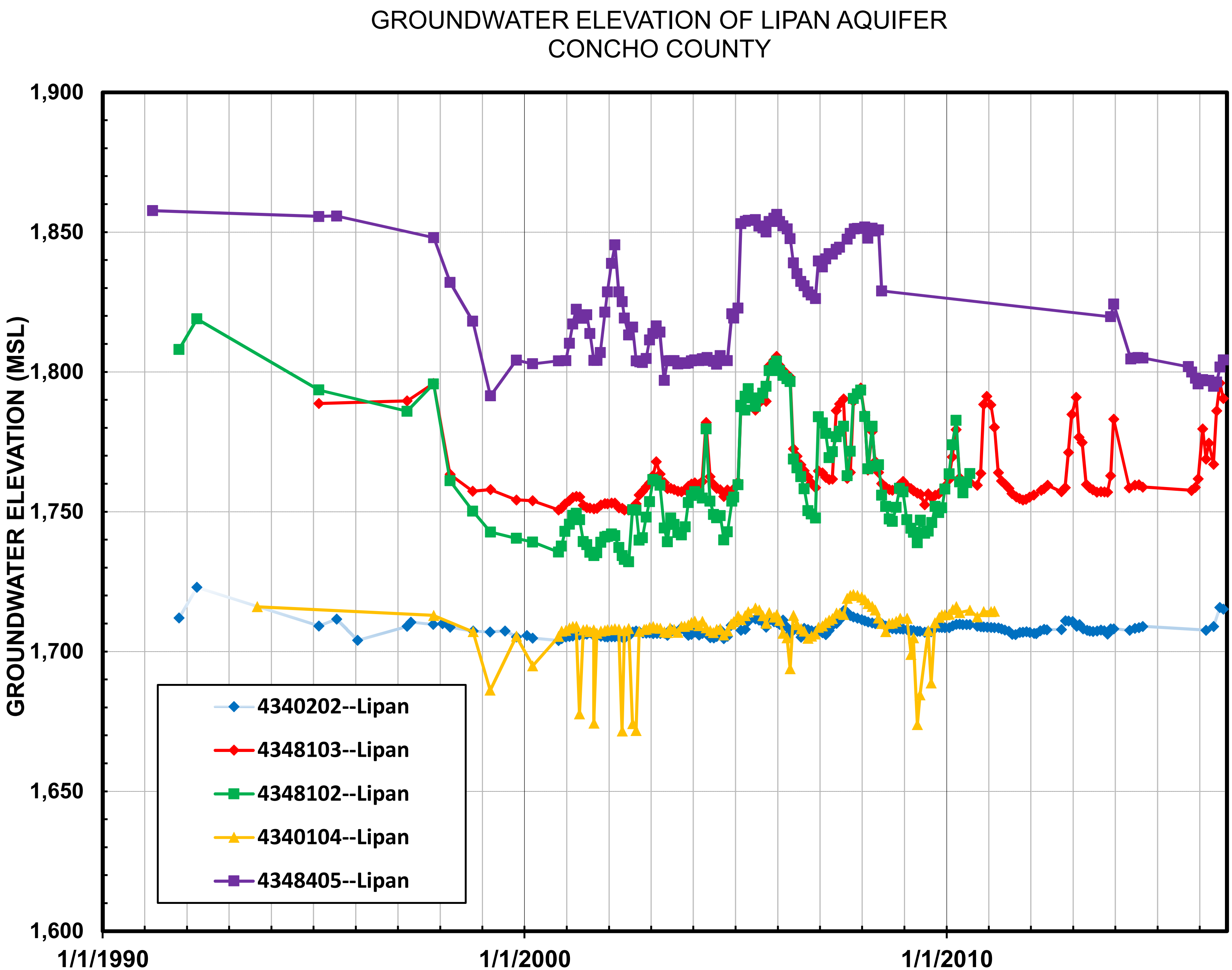

GROUNDWATER ELEVATION OF HICKORY AQUIFER
MCCULLOCH COUNTY
GROUNDWATER ELEVATION (MSL)
1,640
1,620
1,600
1,580
1,560
1,540
1,520
1,500
1/1/1950
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5606614--Hickory
4263802--Hickory
4260902--Hickory
4262902--Hickory
5606610--Hickory
4260601--Hickory

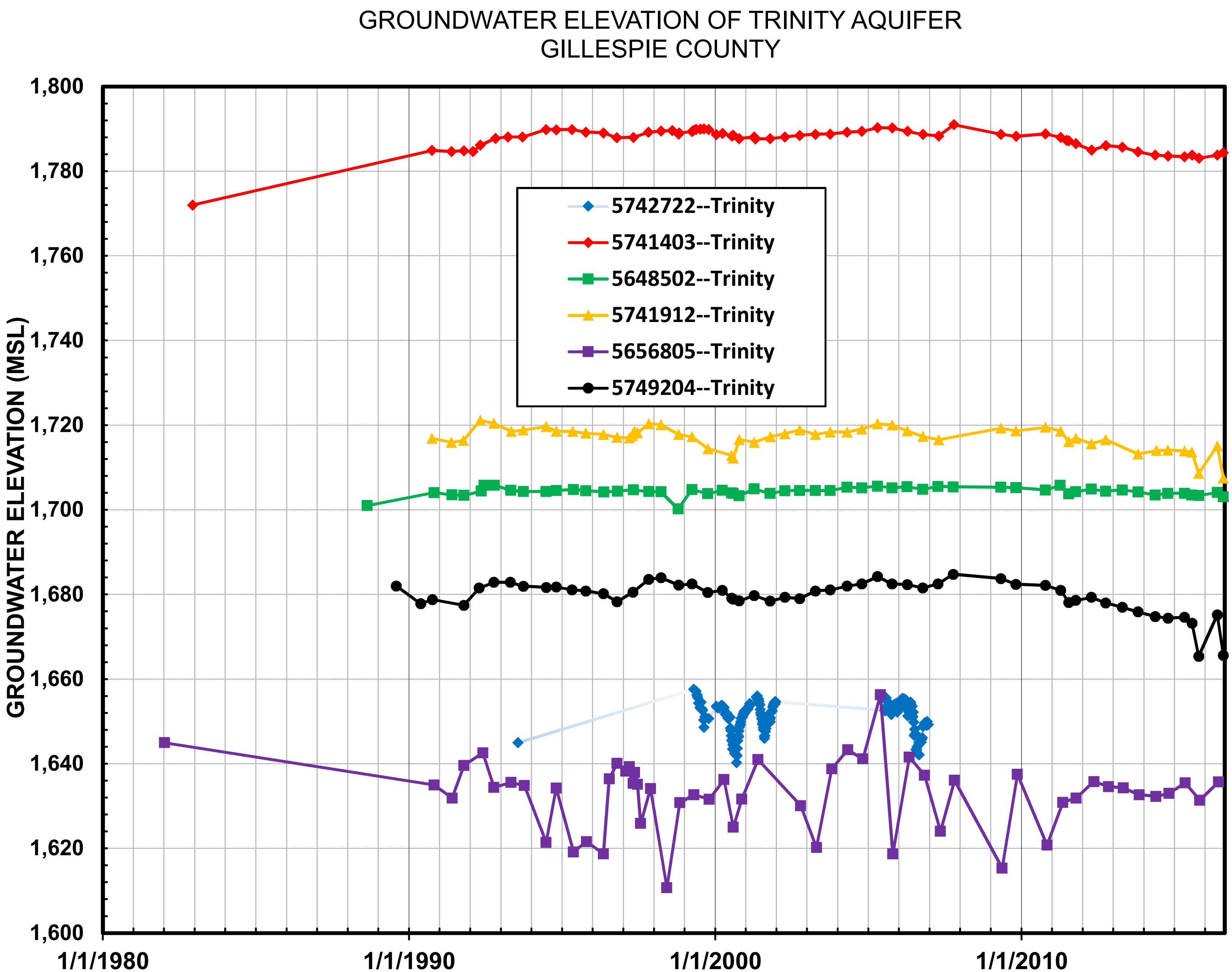

GROUNDWATER ELEVATION OF HICKORY AQUIFER
MASON COUNTY
GROUNDWATER ELEVATION (MSL)
1,700
1,680
1,660
1,640
1,620
1,600
1,580
1,560
1,540
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5606613--Hickory
5606611--Hickory
5613904--Hickory
5614408--Hickory
5614907--Hickory
5606910--Hickory


GROUNDWATER ELEVATION OF HICKORY AQUIFER
MENARD COUNTY
GROUNDWATER ELEVATION (MSL)
1,700
1,680
1,660
1,640
1,620
1,600
1,580
1,560
1,540
1,520
1,500
1/1/1980
1/1/1990
1/1/2000
1/1/2010
4260401--Hickory
5604707--Hickory
5613105--Hickory


GROUNDWATER ELEVATION OF HICKORY AQUIFER
SAN SABA COUNTY
GROUNDWATER ELEVATION (MSL)
1,740
1,720
1,700
1,680
1,660
1,640
1,620
1,600
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5608509--Hickory
5608502--Hickory
5608503--Hickory


GROUNDWATER ELEVATION OF LIPAN AQUIFER
TOM GREEN COUNTY
4345306--Lipan
4337101--Lipan
4337908--Lipan
4346401--Lipan
4346301--Lipan
4337802--Lipan
GROUNDWATER ELEVATION (MSL)
1,900
1,850
1,800
1,750
1,700
1,650
1/1/1950
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010


GROUNDWATER ELEVATION OF LIPAN AQUIFER
CONCHO COUNTY
GROUNDWATER ELEVATION (MSL)
1,900
1,850
1,800
1,750
1,700
1,650
1,600
1/1/1990
1/1/2000
1/1/2010
4340202--Lipan
4348103--Lipan
4348102--Lipan
4340104--Lipan
4348405--Lipan


GROUNDWATER ELEVATION OF TRINITY AQUIFER
GILLESPIE COUNTY
GROUNDWATER ELEVATION (MSL)
1,800
1,780
1,760
1,740
1,720
1,700
1,680
1,660
1,640
1,620
1,600
1/1/1980
1/1/1990
1/1/2000
1/1/2010
5742722--Trinity
5741403--Trinity
5648502--Trinity
5741912--Trinity
5656805--Trinity
5749204--Trinity

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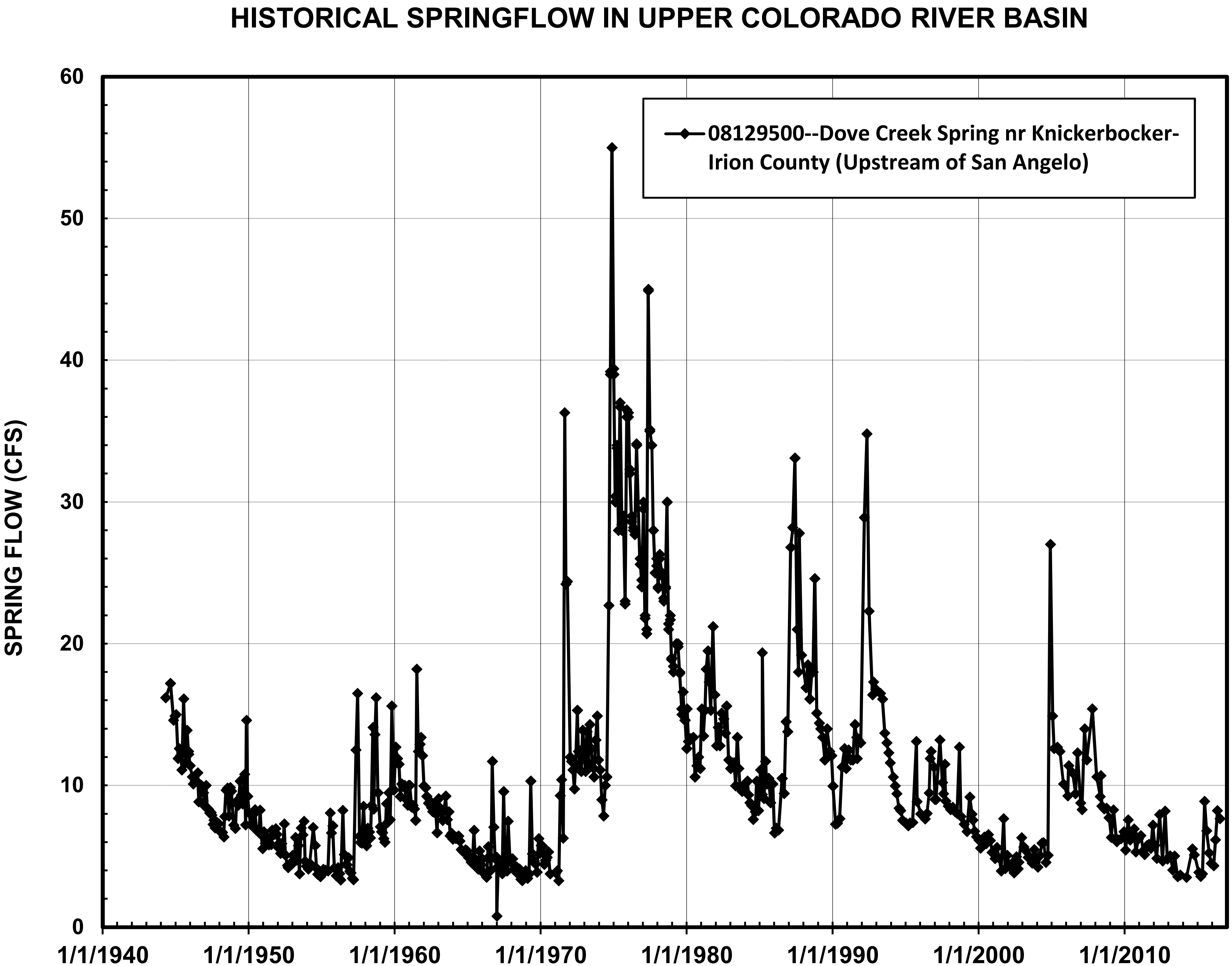
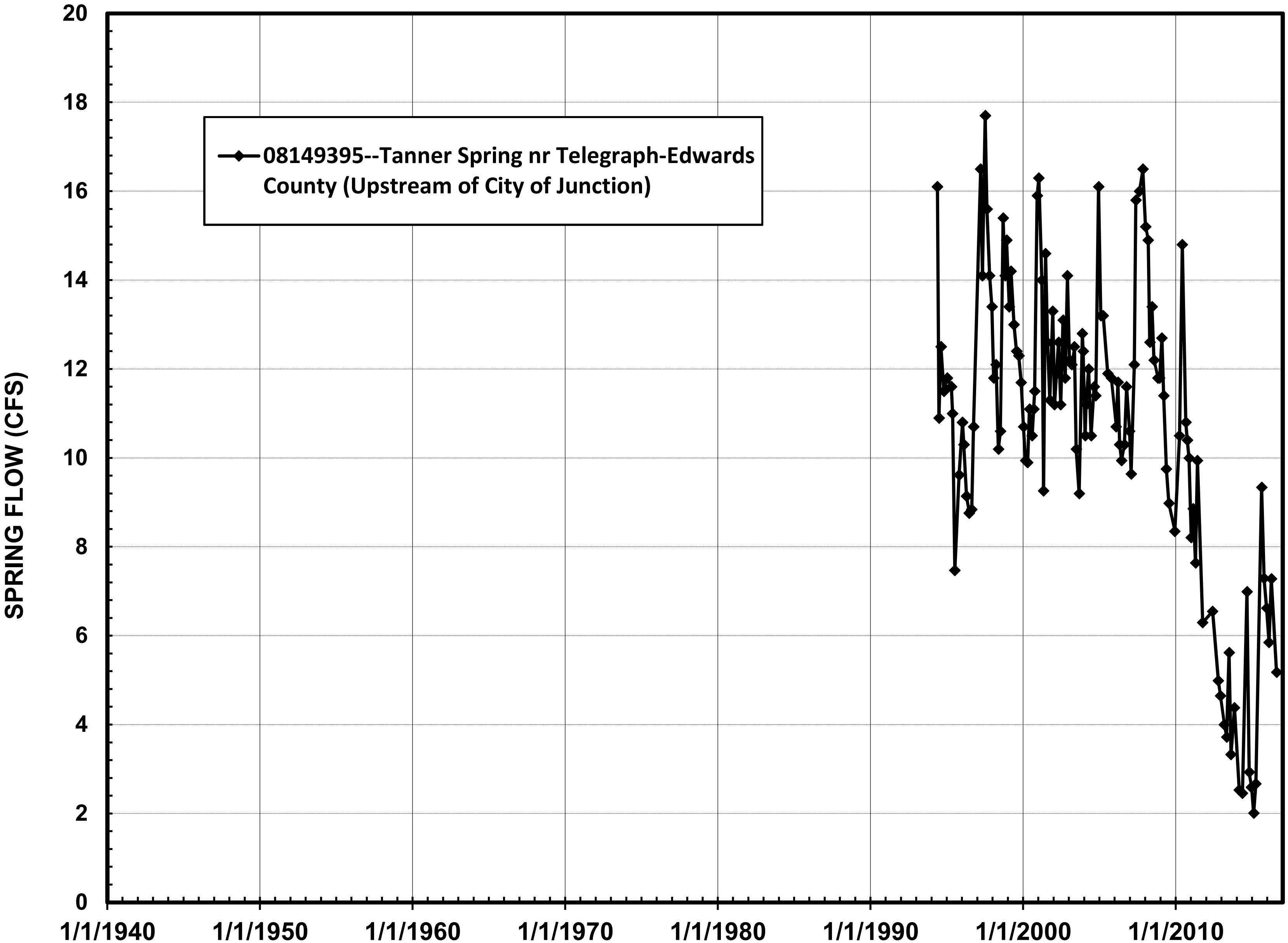
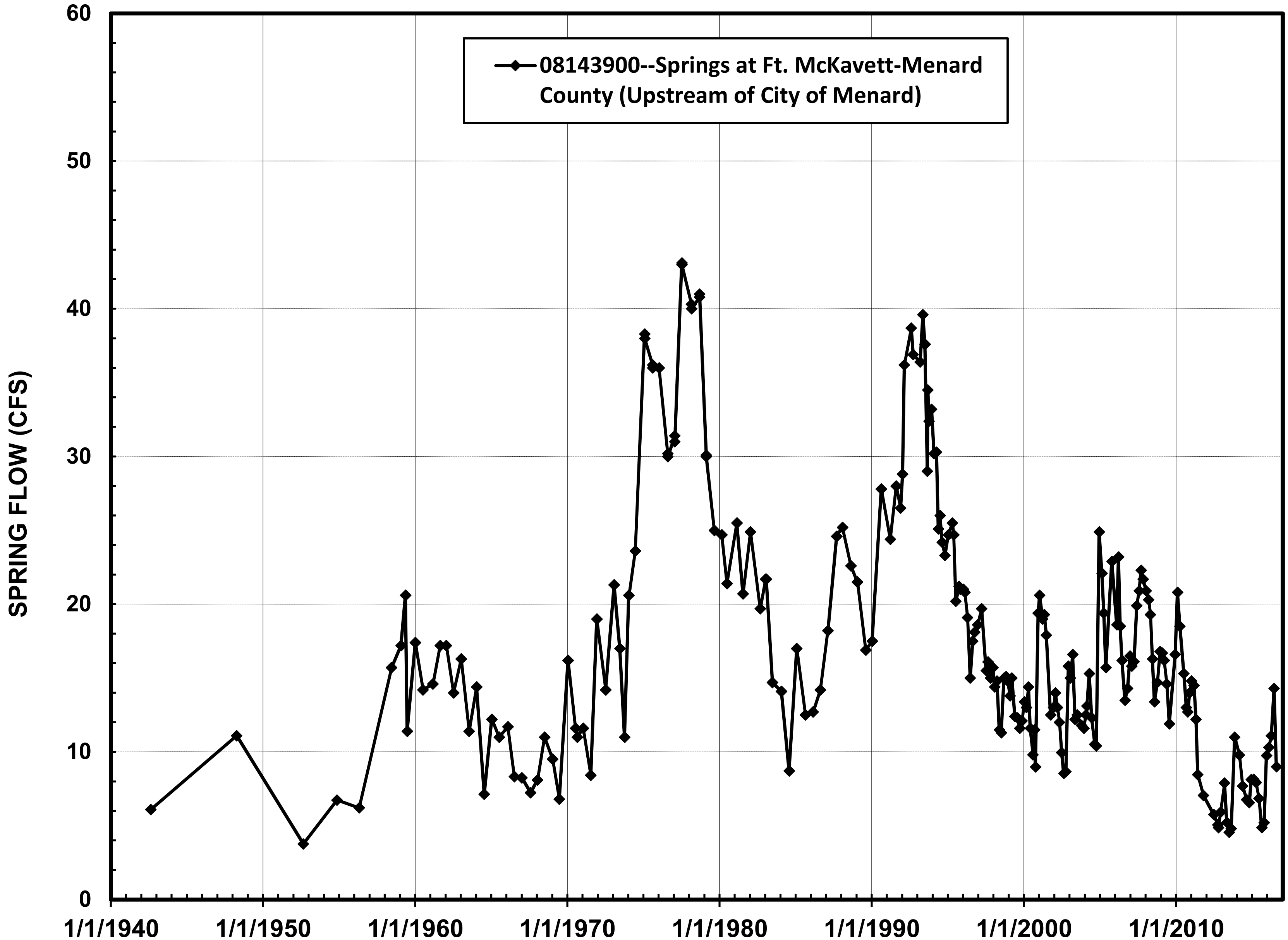

HISTORICAL SPRINGFLOW IN UPPER COLORADO RIVER BASIN
08129500--Dove Creek Spring nr Knickerbocker-Irion County (Upstream of San Angelo)
SPRING FLOW (CFS)
0
10
20
30
40
50
60
1/1/1940
1/1/1950
1/1/1960
1/1/1970
1/1/1980
1/1/1990
1/1/2000
1/1/2010

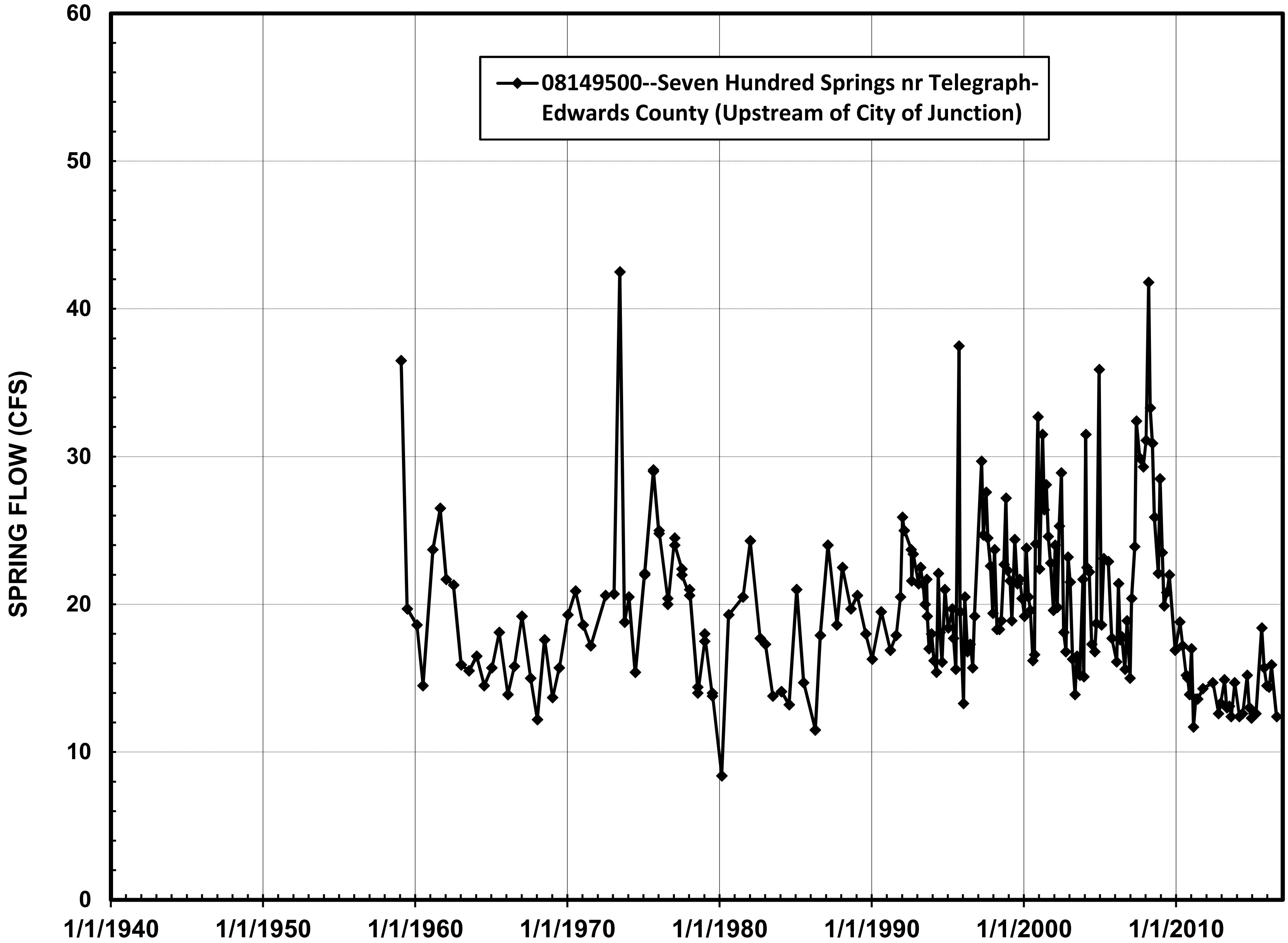
HISTORICAL SPRINGFLOW IN UPPER COLORADO RIVER BASIN



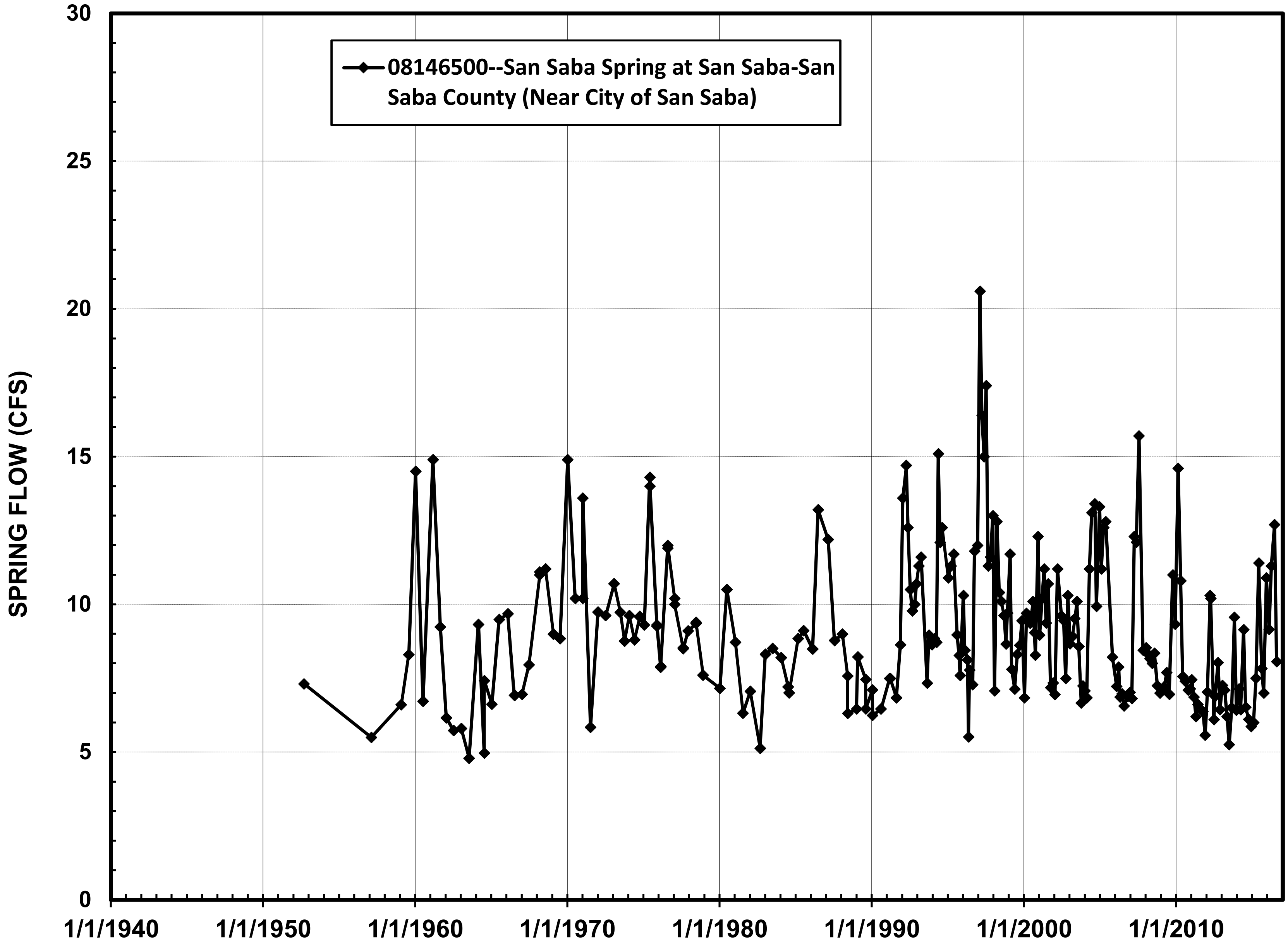
HISTORICAL SPRINGFLOW IN UPPER COLORADO RIVER BASIN



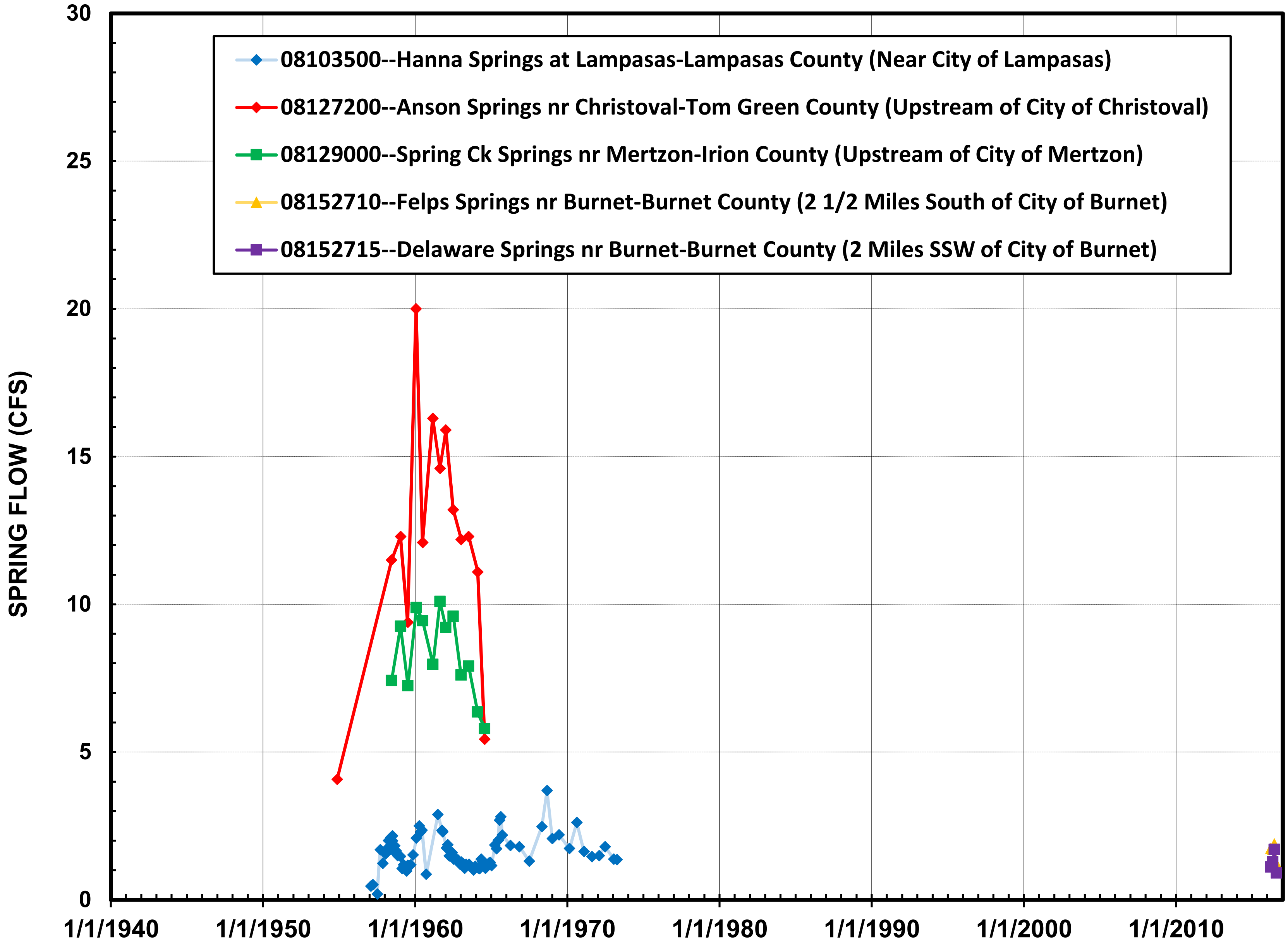
HISTORICAL SPRINGFLOW IN UPPER COLORADO RIVER BASIN

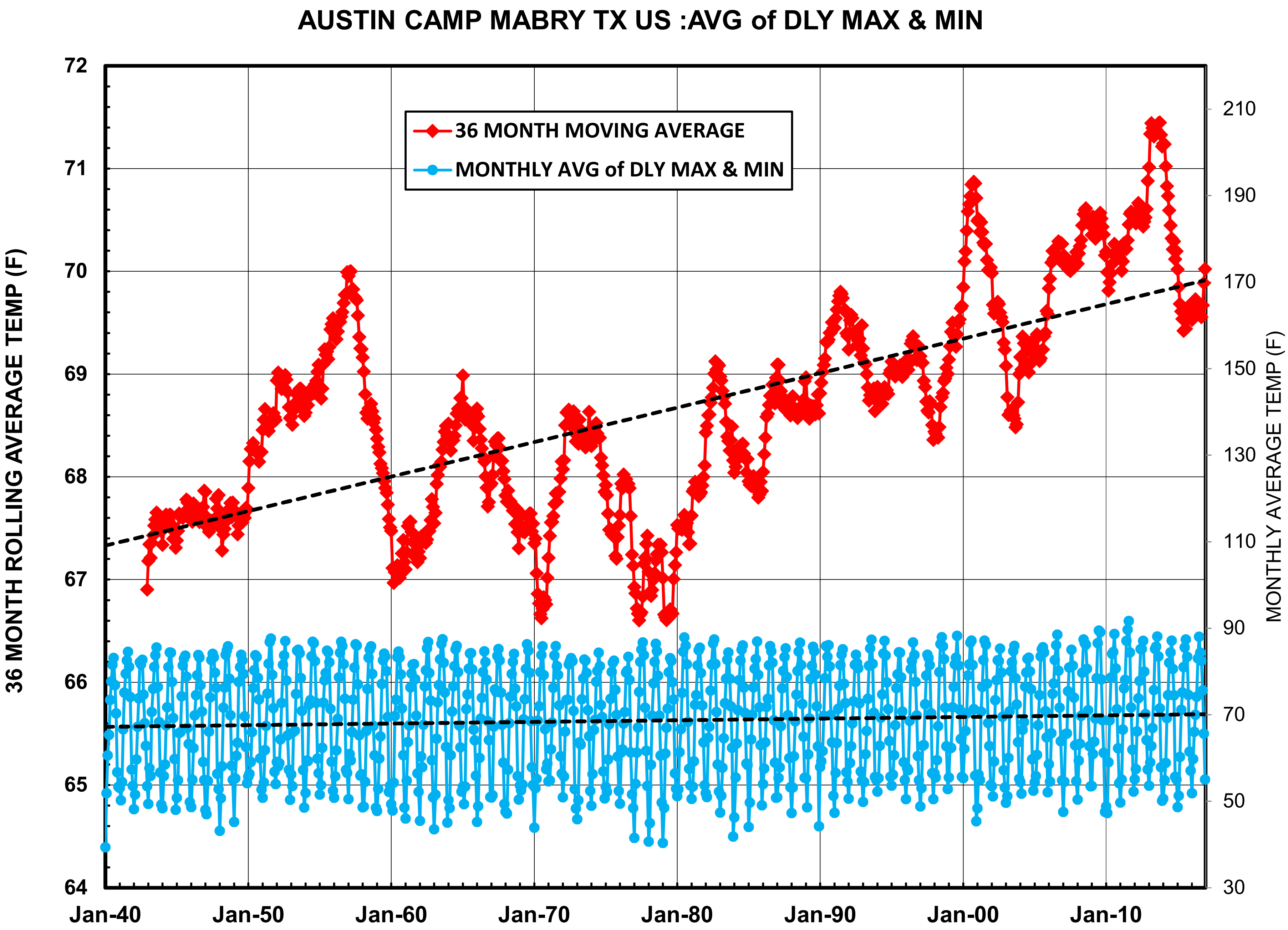


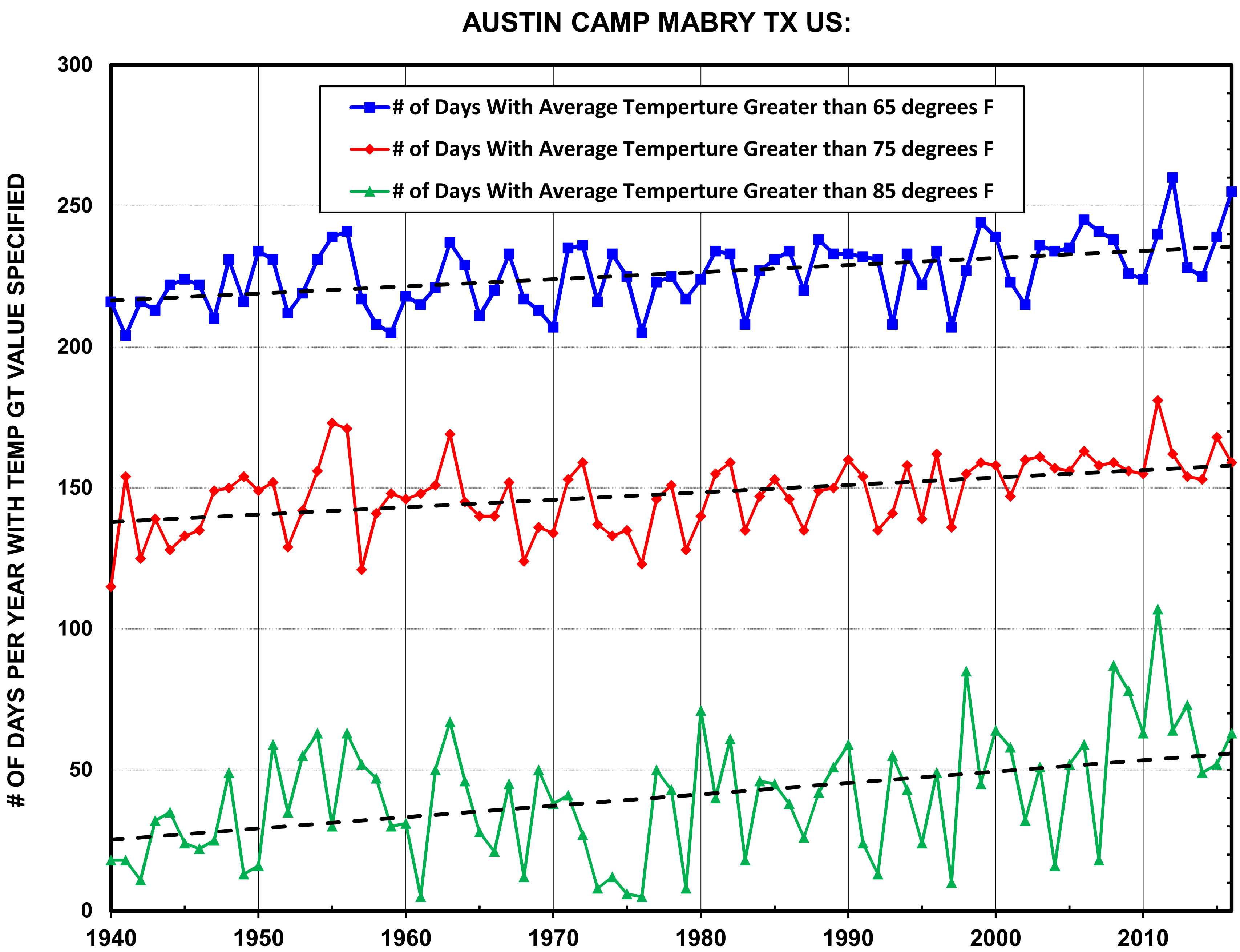
HISTORICAL SPRINGFLOW IN UPPER COLORADO RIVER BASIN



HISTORICAL SPRINGFLOW IN UPPER COLORADO RIVER BASIN




AUSTIN CAMP MABRY TX US :AVG of DLY MAX & MIN
36 MONTH MOVING AVERAGE
MONTHLY AVG of DLY MAX & MIN
36 MONTH ROLLING AVERAGE TEMP (F)
MONTHLY AVERAGE TEMP (F)
72
71
70
69
68
67
66
65
64
210
190
170
150
130
110
90
70
50
30
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


AUSTIN CAMP MABRY TX US:
# of Days With Average Temperture Greater than 65 degrees F
# of Days With Average Temperture Greater than 75 degrees F
# of Days With Average Temperture Greater than 85 degrees F
OF DAYS PER YEAR WITH TEMP GT VALUE SPECIFIED
300
250
200
150
100
50
0
1940
1950
1960
1970
1980
1990
2000
2010

Austin Camp Maybry: Calc. Daily Average Temp (Average of Daily Max and Min)

DECADE	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2016
% OF TIME	GREATER THAN OR EQUAL TO (defrees F)							
0%	90.00	92.50	92.00	92.50	92.50	92.50	95.00	96.00
1%	88.00	89.00	88.50	88.00	89.00	89.00	90.50	92.00
2%	87.00	88.50	88.00	87.00	88.50	88.50	89.50	91.00
3%	86.50	88.00	87.50	86.50	88.00	88.00	89.00	90.00
4%	86.00	87.50	87.00	86.00	87.50	87.50	89.00	90.00
5%	85.50	87.50	86.50	86.00	87.50	87.50	88.50	89.50
6%	85.50	87.00	86.50	85.50	87.00	87.00	88.00	89.00
7%	85.00	86.50	86.00	85.00	86.50	86.50	87.50	88.50
8%	85.00	86.50	85.50	85.00	86.50	86.50	87.50	88.50
9%	84.50	86.00	85.50	84.50	86.00	86.00	87.00	88.00
10%	84.50	86.00	85.00	84.00	86.00	85.50	86.50	87.70
11%	84.00	85.50	85.00	84.00	85.50	85.50	86.00	87.50
12%	84.00	85.50	84.50	84.00	85.00	85.00	86.00	87.00
13%	83.50	85.00	84.50	83.50	85.00	85.00	85.50	86.50
14%	83.50	85.00	84.00	83.50	84.50	84.50	85.50	86.50
15%	83.00	84.50	84.00	83.00	84.50	84.50	85.00	86.00
16%	83.00	84.50	83.50	83.00	84.00	84.00	85.00	86.00
17%	83.00	84.00	83.08	82.50	84.00	84.00	84.50	85.50
18%	82.50	84.00	83.00	82.50	83.50	83.50	84.00	85.50
19%	82.00	83.50	82.50	82.00	83.50	83.50	84.00	85.00
20%	82.00	83.50	82.50	82.00	83.00	83.00	83.50	85.00
21%	81.50	83.00	82.00	81.50	83.00	83.00	83.50	84.50
22%	81.50	83.00	81.50	81.50	82.50	83.00	83.00	84.00
23%	81.00	82.50	81.50	81.00	82.50	82.50	83.00	84.00
24%	80.50	82.50	81.00	81.00	82.00	82.50	82.50	83.50
25%	80.00	82.00	81.00	80.50	81.50	82.00	82.50	83.50
26%	80.00	81.50	80.50	80.00	81.50	81.50	82.00	83.00
27%	79.50	81.00	80.00	80.00	81.00	81.50	81.50	82.50
28%	79.00	80.50	80.00	79.50	80.50	81.00	81.00	82.50
29%	78.50	80.00	79.50	79.00	80.00	80.50	81.00	82.00
30%	78.50	80.00	79.00	78.50	80.00	80.00	80.50	81.50
31%	78.00	79.50	78.50	78.00	79.50	80.00	80.00	81.00
32%	77.50	79.00	78.50	77.50	79.00	79.50	79.50	80.50
33%	77.00	78.50	78.00	77.50	78.50	79.00	79.50	80.00
34%	77.00	78.00	77.50	77.00	78.00	78.50	79.00	79.50
35%	76.50	77.50	77.00	76.50	77.50	78.00	78.50	79.00
36%	76.00	77.00	77.00	76.00	77.00	77.50	78.50	79.00
37%	75.50	77.00	76.50	76.00	76.50	77.06	78.00	78.50
38%	75.00	76.00	76.00	75.50	76.00	76.50	77.50	78.00
39%	74.50	76.00	75.50	75.00	75.50	76.00	77.00	77.50
40%	74.50	75.50	75.00	74.50	75.50	75.50	76.60	77.00
45%	72.00	73.00	73.00	72.00	73.50	73.50	74.50	75.00
50%	70.00	70.50	71.00	70.00	71.00	71.00	72.50	72.50
55%	67.50	68.50	68.00	67.50	69.00	68.50	70.00	70.50
60%	64.50	65.50	65.50	65.50	66.50	66.00	67.00	68.00
65%	62.00	63.00	63.00	63.00	63.62	64.00	64.50	65.50
70%	59.00	60.00	60.00	60.00	60.50	61.50	61.50	62.50
75%	56.50	57.50	56.50	57.00	57.50	59.00	59.00	59.50
80%	54.00	54.50	53.00	54.00	54.50	56.00	56.00	56.50
90%	47.50	48.50	46.00	46.50	48.00	50.00	49.50	49.50
100%	13.00	18.50	16.50	22.50	16.50	20.50	27.00	21.50

Less Than 80 Degrees
Gt 80 and LT 85 Degrees
GT 85 Degrees

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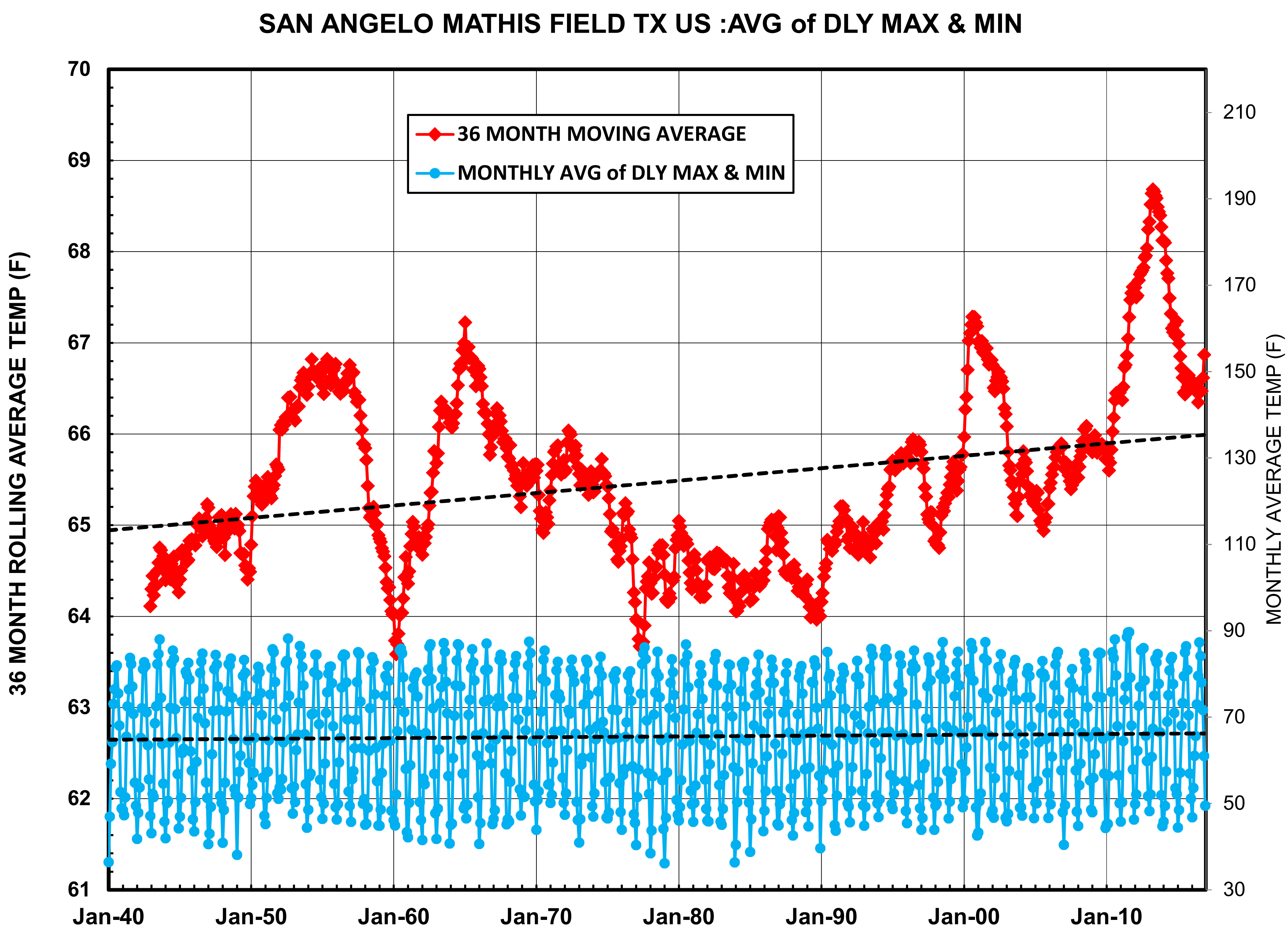
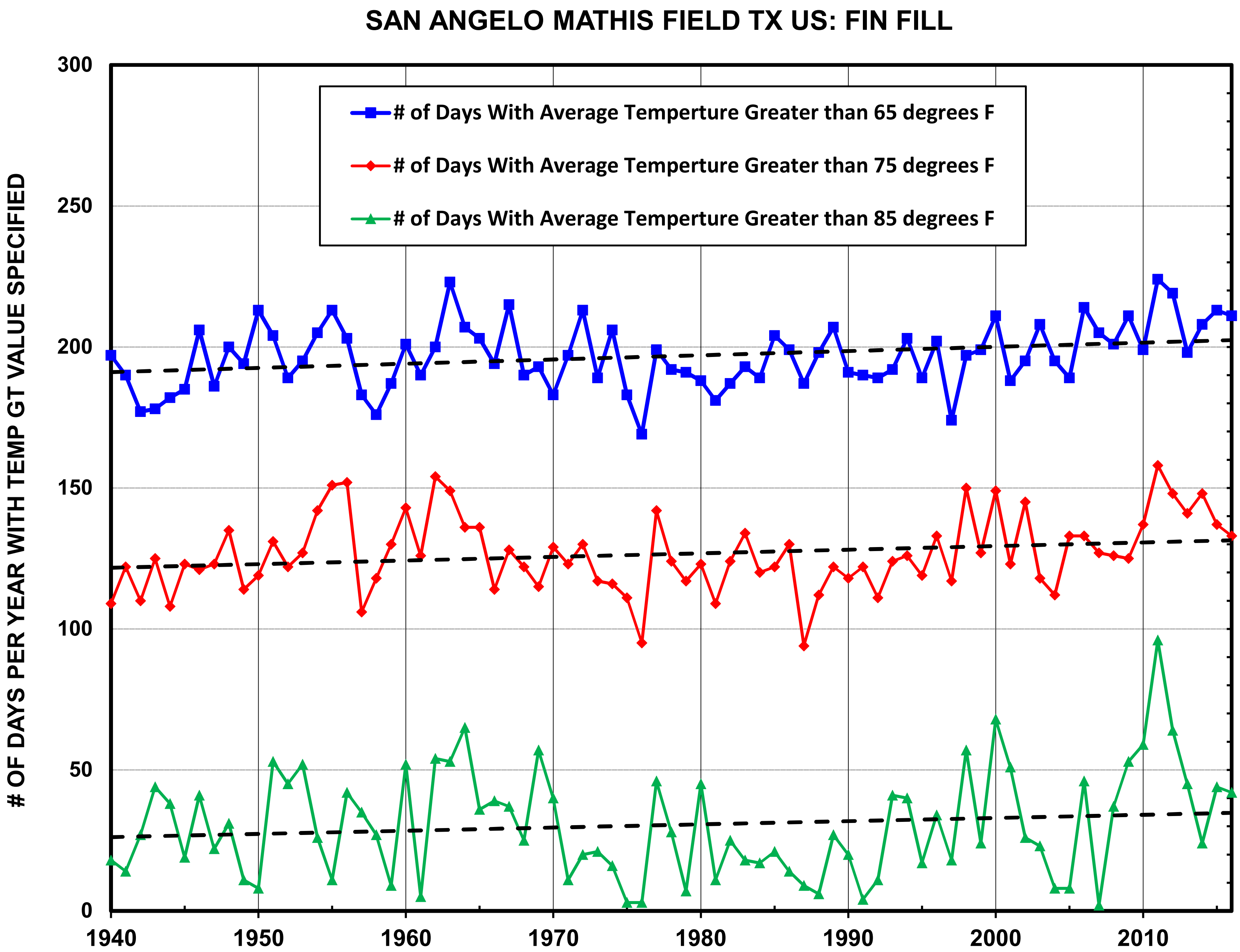

SAN ANGELO MATHIS FIELD TX US :AVG of DLY MAX & MIN
36 MONTH MOVING AVERAGE
MONTHLY AVG of DLY MAX & MIN
36 MONTH ROLLING AVERAGE TEMP (F)
MONTHLY AVERAGE TEMP (F)
70
69
68
67
66
65
64
63
62
61
210
190
170
150
130
110
90
70
50
30
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


SAN ANGELO MATHIS FIELD TX US: FIN FILL
# of Days With Average Temperture Greater than 65 degrees F
# of Days With Average Temperture Greater than 75 degrees F
# of Days With Average Temperture Greater than 85 degrees F
OF DAYS PER YEAR WITH TEMP GT VALUE SPECIFIED
300
250
200
150
100
50
0
1940
1950
1960
1970
1980
1990
2000
2010

San Angelo Mathis Airfield: Calc. Daily Average Temp (Average of Daily Max and Min)

DECADE	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2016
% OF TIME	GREATER THAN OR EQUAL TO (defrees F)							
0%	96.00	92.50	94.50	92.50	93.50	94.50	92.50	95.00
1%	89.00	89.24	90.50	88.50	88.00	90.00	89.50	92.00
2%	88.00	88.00	89.50	87.50	87.00	88.50	88.50	91.00
3%	87.50	87.50	89.00	86.50	86.50	87.50	88.00	90.00
4%	87.00	87.00	88.50	86.00	86.00	87.00	87.50	89.50
5%	86.20	86.50	88.00	85.50	85.50	86.50	87.00	89.00
6%	86.00	86.00	87.50	85.00	85.00	86.00	86.50	88.50
7%	85.50	85.50	87.00	84.50	84.50	85.50	86.00	88.50
8%	85.00	85.50	86.50	84.00	84.00	85.00	85.50	88.00
9%	84.50	85.00	86.00	83.50	83.50	84.50	85.00	87.50
10%	84.00	85.00	86.00	83.50	83.00	84.50	85.00	87.00
11%	84.00	84.50	85.50	83.00	83.00	84.00	84.50	86.50
12%	83.50	84.00	85.00	83.00	82.50	83.50	84.00	86.50
13%	83.00	83.50	84.50	82.50	82.00	83.50	83.50	86.00
14%	82.50	83.50	84.50	82.00	82.00	83.00	83.00	85.50
15%	82.50	83.00	84.00	82.00	81.50	82.50	83.00	85.00
16%	82.00	82.50	83.50	81.50	81.50	82.00	82.50	84.50
17%	81.50	82.50	83.00	81.00	81.00	81.50	82.00	84.50
18%	81.50	82.00	83.00	80.50	80.50	81.50	81.50	84.00
19%	81.00	82.00	82.50	80.50	80.00	81.00	81.50	83.50
20%	80.50	81.50	82.00	80.00	80.00	80.50	81.00	83.50
21%	80.50	81.00	82.00	79.50	79.50	80.50	80.50	82.50
22%	80.00	80.50	81.50	79.00	79.00	80.00	80.00	82.50
23%	79.50	80.50	81.00	79.00	79.00	80.00	80.00	82.00
24%	79.00	80.00	80.50	78.50	78.50	79.50	79.50	82.00
25%	78.50	79.50	80.50	78.00	78.50	79.00	79.00	81.50
26%	78.50	79.50	80.00	78.00	78.00	78.50	79.00	81.00
27%	78.00	79.00	79.50	77.50	77.50	78.00	78.50	80.50
28%	77.50	78.50	79.00	77.00	77.00	78.00	78.00	80.50
29%	77.00	78.00	78.50	76.50	76.50	77.50	77.50	80.00
30%	76.50	77.50	78.00	76.50	76.00	77.00	77.50	79.50
31%	76.00	77.09	77.50	76.00	76.00	76.50	77.00	79.50
32%	75.50	77.00	77.00	75.50	75.50	76.00	76.50	79.00
33%	75.00	76.50	77.00	75.00	75.00	76.00	76.50	78.50
34%	74.50	76.00	76.50	75.00	74.50	75.50	76.00	78.00
35%	74.00	75.50	76.00	74.50	74.00	75.00	75.50	77.50
36%	73.50	75.00	75.50	74.00	73.50	74.50	75.00	77.00
37%	73.50	74.50	75.00	73.50	73.00	74.00	74.50	76.50
38%	73.00	74.00	74.50	73.00	72.50	73.50	74.00	76.00
39%	72.00	73.50	74.00	72.50	72.50	73.00	73.50	75.50
40%	71.50	73.00	73.50	72.00	72.00	72.50	73.00	75.00
45%	69.00	70.50	71.00	69.50	69.00	70.00	70.50	72.00
50%	66.50	67.50	68.00	66.50	66.50	67.00	68.00	69.50
55%	63.50	64.50	65.05	64.50	64.00	64.00	65.50	66.50
60%	60.50	61.50	62.50	62.00	61.50	61.00	62.50	63.50
65%	57.50	59.00	59.50	59.00	58.50	58.50	59.50	61.00
70%	55.00	56.00	56.50	56.00	55.50	56.00	56.50	58.00
75%	52.00	53.50	53.00	53.00	52.00	53.00	53.50	55.50
80%	50.00	50.50	49.50	50.50	49.00	51.00	50.50	51.50
90%	43.50	44.50	42.50	43.00	43.00	44.50	44.00	44.80
100%	11.00	12.50	12.50	16.00	10.00	13.50	22.50	16.00

Less Than 80 Degrees

Gt 80 and LT 85 Degrees

GT 85 Degrees

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** ====================================================================
** KRC 11302016 - ADDED CP'S TO REPRESENT PONDS UPSTREAM OF BRADY GAGE (E20000) THAT ARE NOT ADJUSTED FOR IN NAT
** FLOW PROCESS
** APPROPRIATIVE RIGHT #1 - COMPLETED IN 1912 - NO NEED TO REPRESENT
**CITY OF BRADY
**WRE20010               00000001                                        TX01663-1853
**WSE20010      35   0.911   0.695
** APPROPRIATIVE RIGHT #2 - COMPLETED IN 1958
**ESTATE OF A. H. FLOYD
WRE20100               00000001                                        TX01619-1848
WSE20100     200   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** APPROPRIATIVE RIGHT #3 - COMPLETED IN 1960
**BERNICE KOY
WRE20060               00000001                                        TX01661-1850
WSE20080     175   0.911   0.695
TS   SDL19401959 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19602013       0       0       0       0       0       0       0       0       0       0       0       0
**
** FOLLOWS ARE EXEMPT ONLY RESERVOIRS
** COMPLETED IN 1947
WRE21668               00000001                                             TX01668
WSE21668     101   0.911   0.695
TS   SDL19401946 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19472013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1954
WRE21675               00000001                                             TX01675
WSE21675       6   0.911   0.695
TS   SDL19401953 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19542013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1955
WRE21621               00000001                                             TX01621
WSE21621      31   0.911   0.695
TS   SDL19401954 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19552013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1955
WRE21627               00000001                                             TX01627
WSE21627     120   0.911   0.695
TS   SDL19401954 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19552013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1955
WRE21639               00000001                                             TX01639
WSE21639     159   0.911   0.695
TS   SDL19401954 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19552013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1955
WRE21640               00000001                                             TX01640
WSE21640      24   0.911   0.695
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TS   SDL19401954 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19552013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1955
WRE21662                00000001                                        TX01662
WSE21662      89   0.911   0.695
TS   SDL19401954 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19552013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1955
WRE21676                00000001                                        TX01676
WSE21676      72   0.911   0.695
TS   SDL19401954 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19552013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1955
WRE21678                00000001                                        TX01678
WSE21678      38   0.911   0.695
TS   SDL19401954 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19552013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1956
WRE21629                00000001                                        TX01629
WSE21629     195   0.911   0.695
TS   SDL19401955 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19562013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1956
WRE21658                00000001                                        TX01658
WSE21658     188   0.911   0.695
TS   SDL19401955 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19562013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1956
WRE21664                00000001                                        TX01664
WSE21664     105   0.911   0.695
TS   SDL19401955 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19562013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1956
WRE21665                00000001                                        TX01665
WSE21665      94   0.911   0.695
TS   SDL19401955 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19562013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1956
WRE21670                00000001                                        TX01670
WSE21670     197   0.911   0.695
TS   SDL19401955 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19562013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21618                00000001                                        TX01618
WSE21618     121   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21626                00000001                                        TX01626
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WSE21626     200   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21628                00000001                                        TX01628
WSE21628      75   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21632                00000001                                        TX01632
WSE21632     145   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21633                00000001                                        TX01633
WSE21633      52   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21656                00000001                                        TX01656
WSE21656     115   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21671                00000001                                        TX01671
WSE21671     110   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1957
WRE21674                00000001                                        TX01674
WSE21674      53   0.911   0.695
TS   SDL19401956 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19572013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1958
WRE21616                00000001                                        TX01616
WSE21616     191   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1958
WRE21623                00000001                                        TX01623
WSE21623     198   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1958
WRE21624                00000001                                        TX01624
WSE21624      20   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1958
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WRE21625                00000001                                        TX01625
WSE21625     189   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1958
WRE21654                00000001                                        TX01654
WSE21654     115   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1958
WRE21655                00000001                                        TX01655
WSE21655     108   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1958
WRE21673                00000001                                        TX01673
WSE21673      84   0.911   0.695
TS   SDL19401957 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19582013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1959
WRE21614                00000001                                        TX01614
WSE21614     101   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1959
WRE21617                00000001                                        TX01617
WSE21617     200   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1959
WRE21620                00000001                                        TX01620
WSE21620      80   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1959
WRE21622                00000001                                        TX01622
WSE21622      94   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1959
WRE21630                00000001                                        TX01630
WSE21630     185   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1959
WRE21631                00000001                                        TX01631
WSE21631      75   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
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** COMPLETED IN 1959
WRE21669                00000001                                        TX01669
WSE21669     126   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1959
WRE21672                00000001                                        TX01672
WSE21672      82   0.911   0.695
TS   SDL19401958 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19592013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1960
WRE21660                00000001                                        TX01660
WSE21660      86   0.911   0.695
TS   SDL19401959 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19602013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1961
WRE22310                00000001                                        TX02310
WSE22310      98   0.911   0.695
TS   SDL19401960 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19612013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1962
WRE21677                00000001                                        TX01677
WSE21677     277   0.911   0.695
TS   SDL19401961 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19622013       0       0       0       0       0       0       0       0       0       0       0       0
** COMPLETED IN 1969
WRE21615                00000001                                        TX01615
WSE21615     294   0.911   0.695
TS   SDL19401968 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999 9999999
TS   SDL19692013       0       0       0       0       0       0       0       0       0       0       0       0
** ====================================================================
**
** ====================================================================
** KRC 11302016 - DETERMINE REGULATED FLOW AFTER PONDS HAVE BEEN SIMULATED AND CALL IT NAT FLOW ADJUSTED.
WRA-ZERO                00000001                                   ADF-NF-E20000
TO     2             ADD                 E20000
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EXHIBIT B

SCOPE OF WORK

OVERVIEW

The Colorado/Lavaca BBASC has noted that the relationship between rainfall and river flows may have changed over time in some areas of the upper Colorado River Basin in Texas (Appendix 1). Although this area is known to have recently been in a substantial drought cycle, it is not clear that the reasons for low streamflows in recent decades are completely explained by drought. Specifically, the Colorado BBASC and TWDB are seeking to identify potential reasons for the apparent decline in flows in the upper Colorado Basin and to gain a better understanding of the apparent change in the relationship between rainfall and streamflow. The primary objective of this Scope of Work is to review relevant and available long term observed hydrologic data: (1) to determine if in fact there has been a change in the relationship between streamflow and precipitation, and if so, (2) to develop an explanation/understanding of the reasons for this change. The TWDB has been directed to fund and manage this study. A general scope of work, which is attached as Appendix 2, was previously provided by TWDB.

SUMMARY OF APPROACH

Kennedy Resource Company (KRC) plans to undertake the analysis beginning with the development of an inventory of all appropriate and available long term observed hydrology information (streamflow, precipitation, groundwater levels) in the Colorado River Basin upstream of Lakes Buchanan and Travis (study area). In addition, TCEQ WAM naturalized flows as well as WAM simulated flows from a natural priority current conditions WAM run will be obtained for all of the streamflow gage locations in the study area. Historical streamflows for the 10 upper Colorado River Basin sites where the BBASC made environmental flow recommendations will be obtained along with historical streamflow data from other nearby locations that have observed data for a period of record of at least 40 years. Various monthly statistics will be developed for observed streamflow, naturalized flow, WAM simulated flow, and observed precipitation for the entire period of record (1940-2015, to the extent possible) and separately for an early and late period of record (early and late periods to determined once data is assembled).

This information will be reviewed, and areas of the basin that show substantial differences between the early and late periods of record will be selected for in-depth analysis. Such in-depth analysis will involve review of naturalized flow information from TCEQ's WAM for the Colorado River Basin, simulated flows from the WAM current conditions simulation (Run 8), historical diversions/depletions by existing water rights in the watershed, and groundwater levels in the region. For sites that show substantial statistical differences between early and late periods that are not explained by the above, the appropriate precipitation stations will be associated with streamflow gaging stations and analyses of daily streamflow volumes versus daily rainfall quantities will be conducted. Information relating to streamflow and precipitation distribution, magnitude, and timing will be analyzed for each site and compared over the entire period of record to determine if the relationships have significantly changed over time. Where necessary and possible, incremental watershed areas between streamflow gages will be isolated and analyzed separately. Areas of the basin, or portions of watersheds between streamflow gages, that show clear deviations in the precipitation to streamflow relationship will be further examined by reviewing and analyzing current land use coverage information in the subject watersheds such as (a) the occurrence and density of phreatophytes and/or other water consuming brush varieties and (b) an assessment of the number of small stock ponds and reservoirs (those exempt from water rights permitting requirements) present in the watershed. The BBASC and TWDB will be updated as the analysis progresses and findings will be shared with regional experts. A final report will be written detailing the results of the investigation.

Following is a list of tasks and subtasks anticipated to be undertaken pursuant to completion of the work, with the expected level of effort for each of the tasks expressed as a percentage of the overall project effort.

TASKS

Task 1: Create Data Inventory of Information Available in the Study Area (4%)

(1) Create a list of the following observed hydrology information:
   (a) USGS gaging stations for the 10 sites the BBASC made environmental flow recommendations for.
   (b) Up to 3 other gaging station sites (USGS, LCRA, other) in the study area that have at least 40 years of observed data available.
   (c) Long term precipitation recording stations in or near the study area.
   (d) Groundwater monitoring wells in the study area.
   (e) Major springs located in or near the study area.
(2) Create a timeline of major reservoir construction in the study area with the size of impoundment and date of first impoundment noted.

Task 2: Review Past and Ongoing Efforts in the Study Area (6%)

(1) Research previous studies describing all documented past and present efforts that address rainfall/streamflow relationships in the area of interest.
(2) Research previous studies dealing specifically with phreatophyte infestation and/or other water consuming brush varieties, NRCS reservoir construction, livestock pond construction, rural electric meter installation specifically designated for wells, and land use changes to the extent such information is available and can be reasonably obtained.
(3) Contact (via telephone) representatives of large municipalities, river authorities, and water districts in the region to get their input on possible reasons for changes in rainfall versus streamflow.

Task 3 – Analyze Hydrology Information (60%)

(1) Extract naturalized flows from TCEQ's WAM for all primary control point locations (gages) in the study area.
(2) Extract regulated flow from TCEQ's current conditions WAM (executed with natural priority option) for all primary control points in the study area.
(3) Analyze historical flows and naturalized flows for each of the streamflow gages identified in Task 1 and identify all sites that show declining historical streamflows over time using cumulative mass curves.
(4) Review historical water right diversion information and major reservoir construction dates for the watersheds upstream of stations identified in Task 3(3).
(5) Review available groundwater level information in the vicinity of the stations identified in Task 3(3).
(6) Identify sites that show the most deviation in streamflow/precipitation relationships between the early and late time periods that is not explained by findings from Tasks 3(4) and 3(5).
(7) Select and/or develop companion precipitation stations for the gaging stations identified in Task 3(6).
(8) Using daily records, develop streamflow and precipitation statistics for common periods of time (entire period, early period, late period) for the sites identified in Task 3(6) and compare results between the various periods of time.
(9) Associate representative precipitation stations with the streamflow gages identified in Task 1 and identify precipitation trends over time.
10) Identify single site from Task 3(8) that shows the most deviation in streamflow/precipitation relationships between early and late time periods and use available investigations and reports, GIS information and aerial photography to review:
    (a) The approximate watershed areas infested with phreatophytes and/or other water consuming brush varieties.
    (b) The approximate drainage area controlled by exempt reservoirs.

Task 4: Share Findings with Regional Experts (4%)

(1) The findings determined for the locations identified in Task 3 will be made available to representatives from large municipalities, river authorities, and water districts in the region. Conference calls will be scheduled with these individuals to discuss their findings, and all comments will be considered in finalizing study results.

Task 5: Meet with TWDB and BBASC to Discuss Study Results (9%)

(1) Meet with TWDB and BBASC to discuss findings (up to 2 meetings in Austin).
(2) Discuss additional analysis needed to investigate the causes of changes in precipitation/streamflow relationships.
(3) Discuss locations where additional streamflow gages, monitoring wells, or precipitation stations would provide meaningful future information to address the precipitation/streamflow issue.

Task 6: Prepare Report and Finalize Results and Recommendations (17%)

(1) Prepare and submit draft report to TWDB summarizing all findings and conclusions.
(2) Respond to and address TWDB comments on draft report.
(3) Prepare and submit to TWDB final report to TWDB summarizing all findings and conclusions and include electronic copies of models and data.

EXHIBIT C

TASK AND EXPENSE BUDGETS AND PROJECT TIMELINE

TASK BUDGET

TASK	DESCRIPTION	TWDB AMOUNT
TASK 1	Create Data Inventory of Information Available in the Study Area	865
TASK 2	Review Previous and Ongoing Efforts in the Study Area	1155
TASK 3	Analyze Hydrology Information	12085
TASK 4	Share Findings with Regional Experts	825
TASK 5	Meeting with TWDB and BBASC to Discuss Study Results	1750
TASK 6	Prepare Report and Finalize Results and Recommendations	3320
Total		**20000**

EXPENSE BUDGET

CATEGORY	TWDB AMOUNT
Salaries and Wages[1]	$15510
Fringe[2]	
Travel[3]	100
Other Expenses[4]	90
Subcontract Expenses	4300
Overhead[5]	
Profit	
TOTAL	**20000**

[1] Salaries and Wages is defined as the cost of salaries of engineers, draftsmen, stenographers, surveymen, clerks, laborers, etc., for time directly chargeable to this CONTRACT.
[2] Fringe is defined as the cost of social security contributions, unemployment, excise, and payroll taxes, workers' compensation insurance, retirement benefits, medical and insurance benefits, sick leave, vacation, and holiday pay applicable thereto.
[3] Travel is limited to the maximum amounts authorized for state employees by the General Appropriations Act, Tex. Leg. Regular Session, 2015, Article IX, Part 5, as amended or superseded
[4] Other Expenses is defined to include expendable supplies, communications, reproduction, postage, and costs of public meetings directly chargeable to this CONTRACT.

[5] Overhead is defined as the costs incurred in maintaining a place of business and performing professional services similar to those specified in this CONTRACT.

PROJECT TIMELINE

Upon execution of contract (no later than November 18, 2016)	Begin analysis
June 30, 2017	Provide draft report to TWDB staff
July 31, 2017	Receive comments from TWDB staff
August 31, 2017	Provide final report to TWDB staff

Attachment 1
Kennedy Resource Company
Evaluation of Rainfall/Runoff Patterns in the Upper Colorado River Basin
TWDB Contract 1600012011
TWDB Comments to Final
Report

NOTE: KRC's response to TWDB's comments are imbedded below each comment in bold italic underline.

REQUIRED CHANGES

General Draft Final Report Comments:

Overall, this study thoroughly addressed the goals and objectives outlined in the Scope of Work. The author noted where data limitations prevented further analysis, such as the lack of information on authorized and exempt small reservoir construction or only a couple years of increased rainfall after brush control activities in the 2000's. Even with the data limitations, the report appears to support the conclusion that rainfall-runoff declines are apparent in most of the study sites and are likely the result of increased authorized water use (authorized major reservoirs, and authorized diversions) as well as varying degrees of effect from the other four activities investigated: proliferation of brush, construction of small reservoirs, declines in groundwater levels, and changes in temperature changes or the appearance of recent extreme drought conditions.

The report does an excellent and comprehensive job of enumerating and analyzing potential influences that could be contributing to the change in the relationship between rainfall and streamflow in the Upper Colorado Basin in the last decade. Any weaknesses in arriving at definitive conclusions on impacts to flows are a result of deficiencies in availability of requisite data, not of the methodology, thoroughness of review of existing data, or analysis. The two areas in which the report makes evident the necessity for additional data are in regard to the impact of brush control in increasing streamflow and the impact of exempt surface and groundwater use on decreasing them.

It provides a lot of useful analysis and, not surprisingly particularly given the limited budget available, no firm conclusions about specific causes or impacts. The level of analysis required to form such conclusion was beyond the study scope and may be beyond the level of information available at this time.

Specific Draft Final Report Comments:

1) Please add the following disclaimer on the front page of the report:

PURSUANT TO HOUSE BILL 1 AS APPROVED BY THE 84TH TEXAS LEGISLATURE, THIS STUDY REPORT WAS FUNDED FOR THE PURPOSE OF STUDYING ENVIRONMENTAL FLOW NEEDS FOR TEXAS RIVERS AND ESTUARIES AS PART OF THE ADAPTIVE MANAGEMENT PHASE OF THE

SENATE BILL 3 PROCESS FOR ENVIRONMENTAL FLOWS ESTABLISHED BY THE 80TH TEXAS LEGISLATURE. THE VIEWS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE AUTHOR(S) AND DO NOT NECESSARILY REFLECT THE VIEWS OF THE TEXAS WATER DEVELOPMENT BOARD.

The new text has been inserted on the title page of the report.

2) Please correct the contract No. from 16000012011 to 1600012011 in all instances that it appears in the report.

Correction made.

3) Page 56. Section 5.3.2: The modified WAM methodology presented in this section is a new and innovative way to examine the effects of small reservoirs that has not been documented in other reports. The modified WAM methodology is a valuable support for the author's conclusions regarding small authorized and exempt reservoirs. However the report does not provide details on the WAM modifications that were made. Without such specific information, the analysis and conclusions of the report cannot be reviewed for accuracy and reliability.

   a. Please include an appendix containing specific information related to any WAM modifications that were made, including the specific WAM input records. Absent this specific information, the analysis and conclusions cannot be reviewed for accuracy and reliability.

Appendix P has been added to the report, which shows the code created and used in the Colorado WAM input file to facilitate the analysis described in Section 5.3.2.

4) Page iv, Executive Summary, Historical Temperature Changes and Drought Conditions:

   a. Please include the name of the Climate Division that covers most of the study area.

The climatic division has been specified.

   b. Last sentence: change "*factors that influence the precipitation*" to "*factors that influence soil moisture and runoff*".

Correction has been made.

5) List of Appendices: Change "Mas" in title for Appendix D to "Mass".

Correction has been made.

6) Page 8, Section 1.7. Revise the discussion of water use reporting requirements in the last paragraph. Although many of the water rights in the study area are required to submit an annual water use report, some of the water rights in the study area are under the jurisdiction of the Concho Watermaster and are required to report diversions on a real time basis rather than annually.

The narrative has been revised to address the different water use reporting requirements.

7) Page 12, Section 2.2:

a. First sentence: The National Climatic Data Center (NCDC) is now known as the National Centers for Environmental Information (NCEI). Please change the reference to NCDC to NCEI in all instances that it appears throughout the report.

The new name and abbreviation has been adopted throughout the report.

b. Second sentence: Please define what is meant by the statement *"…this coverage was reviewed in the proximity of each study site."*

The phrase has been clarified in the text.

c. One-before-the-last-sentence: Please define *"reasonable periods of records"*.

A footnote has been added to the report explaining this phrase.

8) Page 17, first sentence: Please reword *"man's historical impacts"* to "*historical anthropogenic impacts*".

Requested change has been made.

9) Page 23 and 24, Section 3.2. The last sentence of this section needs revision to remove the reference to appropriative water rights. It is correct to state that TCEQ does not evaluate exempt reservoirs for water availability or to determine whether a new exempt use would affect other exempt uses. However, exempt uses cannot affect appropriative rights because these uses, by statute, are senior and superior to all appropriative rights.

The language in the report is intended to point out that exempt reservoirs impounding water upstream of other users (both domestic and appropriative rights) physically result in less water flowing downstream, resulting in the downstream users receiving less water than they did before the upstream exempt reservoir was put in place. This occurrence is true regardless of priority specified in statute. A few clarifying changes were made to text of the report.

10) Page 33, Section 3.3.4., one-before-the-last paragraph: The statement *".....no existing process readily available..."* is not valid. A raster dataset of land cover can be analyzed to extract areal extents using various spatial statistics tools such as zonal statistics in ArcGIS.

    a. Reword this sentence to state that the work required for such a detailed analysis of areal extent under noxious brush was, due to budgetary constraints, beyond the scope of the current project.

The draft language describes several information sources that have the capability of being manipulated to be used for the quantification of noxious brush acreage and makes the point that none of these data are currently setup to be used in this fashion. An additional clarification was made in the text of this section to clarify that such detailed analysis was beyond the scope of the current project.

11) Page 35, Section 3.4.2. Modify the last sentence on this page to replace "can be significant" with "may be significant" to be consistent with the conclusions in Sections 6.2 and 6.3.

The recommended change has been made.

12) Page 41, Section 3.7, second paragraph, last sentence: A decrease of soil moisture is probably the more likely result of increases in temperature. Reword statement to account for this.

The sentence has been reworded.

13) Page 42, Section 3.9: The statement *"Other than the PDSI information presented in the previous section that relates overall wet and dry conditions over the project period of record, no other information was found that could be used to quantify historical soil moisture conditions in the study site watersheds."* is inaccurate. The Standardized Precipitation Index and the Standardized Precipitation Evaporation Index are other indices with comparable records to the PDSI that can be used for a historical assessment of soil moisture and antecedent cumulative moisture conditions. These indices are comparable across geographic locations are, thus, considered to be more robust than the PDSI, which is not comparable across geographic locations.

    a. Therefore, please reword this statement to state that historical soil moisture conditions were inferred using only the PDSI as a proxy soil moisture dataset.

The text of the report in this section has been modified to point out that historical soil moisture conditions were inferred from PDSI and that there are other approaches could have been used, such as the Standardized Precipitation Index and the Standard Precipitation Evaporation Index.

14) Page 45, Section 4: Please reword title from "*Important Documents Reviewed*" to "*Literature Reviewed*".

The recommended change has been made.

15) Pages 45–48, Section 4: Please include the citation (in the form of <author, year> or <author and others, year>) for each report or journal article cited. Also, please follow
this format of citation in all other instances where references are included throughout the report.

The recommended citation has been inserted at the beginning of each section in chapter 4 and other sections where citation was used.

16) Page 67, Section 6.2.4: Change *"…influence the precipitation…"* to *"….influence the soil moisture and runoff….".*

Correction noted and made.

17) The discussion of Sulphur Draw Reservoir throughout the report should be modified to more correctly reflect the contribution of this reservoir to downstream flow and this reservoir should be removed from Table 3. Water Right Permit 5457 authorizing Sulphur Draw Reservoir states ".. the flow of Sulphur Springs Draw has historically been considered by the Texas Water Commission as **not** (emphasis added) contributing to the remainder of the flow in the Colorado River Basin and, because of the poor quality of the water in the draw, it is the intent of the project requested in the application to maintain this "non-contributing" condition"

The suggested comment appears to be made based on water rights permitting logic, rather than factors that actually influence streamflow conditions over long periods of record. Sulphur Draw Reservoir and the other 3 reservoirs in this watershed were described in the report as being constructed for the primary purpose of preventing poor quality water from entering the basin downstream of their locations. However, before they were built, the water they now impound, on occasion, contributes some amount of flow to the watercourse downstream. Similar to the description of other activities in the upper basin, the construction of these dams within the 1940-2016 period of record has introduced an opportunity to change the flow that would otherwise travel downstream, thus the need for the special explanation. No change was made to the text of the report.

18) Remove blank pages appearing at: page 22, page 44, page 72, after page C1, after page F1, after page G1, after page H1, after page I1, after page L17, after page N3, and after page 03.

The blank pages are deliberate in order to force the start of new chapters to fall on the front side of the double sided format the report was required to conform to. No change was made to remove these blank pages; instead each of these blank pages are now populated with the comment "this page intentionally left blank".

Figures and Tables Comments:

1) Table 4, Small Reservoirs in the Upper Colorado Basin. The number of authorized reservoirs and the capacities in the table for each watershed is not consistent with the number of permitted water rights. If TCEQ's water rights database was used to generate the table entries, please be aware that this database is not intended to reflect all of the authorizations in individual water rights permits. For purposes of this project, information from the WAM and TCEQ's GIS coverage for water rights would provide more accurate information.

The list of small reservoirs in the upper basin in Table 4 was primarily developed using the WAM model files and GIS coverages as the comment recommends, with the TCEQ Water Rights Masterfile being used only to provide additional understanding of some of the more complicated water right arrangements. No summary of this type of information, by WAM subwatershed, was found to be available from TCEQ, thus this information was created as part of this project to provide the reader a better understanding of the extent that existing water rights are authorized to impound water in the various subwatersheds. The text has been modified to make this clearer.

2) Figure and table captions should be in sentence case and not all caps. Please revise font for figure and table captions throughout report.

All figure and table captions in the report have been modified to conform with the mandated format.

3) Table 8, page 22, explanatory sentence enumerated as (1) below table: Please include this in the body of the text or as a foot note to a specific section in the table.

The explanatory sentence was removed from the table with the content of the sentence already adequately explained in the text of the report.

SUGGESTED CHANGES

Specific Draft Final Report Comments:

1) Page 15, Section 2.3: The discussion of naturalized flows could be revised. The naturalized flows are a dataset of hydrologic time series of historical streamflow, modified to remove human water use. The terminology "spreadsheet analysis of historical data outside of the WAM models" could be modified to more accurately reflect how the naturalized flows were developed and to indicate that these flows were created as part of the development of the WAMs and not separate from the WAMs.

The intent of the description of naturalized flows was to (1) ensure the reader understands what the naturalized flows represent and (2) make clear to the reader that the naturalized flows are not a simulated quantity from WAM. In addition, the precise language in the report is accurate in that the process to determine natural flows is not part of the WAM program, although the naturalized flow process was developed for WAM purposes, which is explained in the existing text. The language was modified to make this point more clear.

2) Page 16, Section 2.3.1: The description of RUN8 should be modified for clarity. Historical water use in RUN8 of the Colorado WAM has not been updated for water use in the study area since the WAMs were originally developed.

The description of RUN8 was simply to provide the reader an example of how the WAM model was intended to represent a future demand condition using the past hydrologic variations developed in the naturalized flow process. Since simulation results from neither the RUN3 nor RUN8 versions of the WAM model were relied upon to develop any flows in this report, there does not appear to be any reason to elaborate on the status of either of the WAM models. No changes were made to the report text.

3) Page 21, Section 2.4.4: next-to-last sentence in 1st paragraph: This sentence is a bit difficult to follow. If, as it appears, the conclusion is that some other factor(s), in addition to quantified water right impacts, is/are contributing to the declining trend, it would be helpful to have that stated more explicitly.

The sentence has been reworded to be more clear.

4) Page 24, Section 3.2: It would be good to state that under current state law it will be difficult to obtain accurate quantification of the extent of the increase in exempt domestic and livestock use, both riparian and groundwater, to determine its impact on streamflow. The rationale for including such a statement is as follows:

> Table 10 on page 34 in Section 3.4.1 shows population declines since 1940 in the counties in the San Saba watershed ranging from -25.4 %in Mason County to -
> 50.4 % in Menard County. Tables 11A and 11B on page 35 in Section 3.4.2 show the fragmentation of larger properties into many smaller tracts. Table 12 on page 35 in Section 3.4.3 shows substantial decrease in numbers of head of livestock in each county since 1975. Appendix H, Summary of Cultivated Acres, Page H-1 shows a substantial decline in the number of acres of crops grown in most counties since 2000. All these trends taken together — fewer people, less irrigation, and less livestock water use — would seem to indicate there has been a decline in water use.
>
> However, what the data does not account for is that many of the rural counties now have extensive non-resident landownership — more than 60% of Menard County landowners are non-resident, for instance — who come for recreation on

week-ends or for hunting season, and/or have residents managing their livestock or wildlife operations. They are more likely than resident farmers or ranchers to use exempt groundwater wells for ponds on their land or their riparian domestic and livestock exemption for impoundments on their creeks. See Section 3.2.1.2. With smaller tracts, there are a larger number of wells. Appendix I, page I-1 shows that the number of wells drilled in the area around each site has increased significantly since 2002.

All wells that are drilled, including exempt wells, are reported to the TCEQ. However, the exempt use from those wells is not required to be reported.

The report already states that existing law regarding uses of water for exempt purposes requires no water use reporting or reporting of exempt reservoir size or location. The text has been altered to include additional clarity reiterating that since there are no specific reporting requirements, it is difficult to quantify the extent to which increases in exempt water uses have impacted streamflow.

5) Page 30, Section 3.3: This section and the overall report would benefit from including a definition for the term noxious brush. (Also true for Section 6.2.1 on p. 66).

The term "noxious brush" is the term used by the by the Texas State Soil and Water Conservation Board (TSSWCB) to refer to brush varieties that are "detrimental to water conservation". To respond to this comment, the question was specifically put to the TSSWCB staff. Their response was that the term is site specific to what an agriculture landowner might consider noxious to grazing, water use, etc. A footnote has been added to the report defining this term.

6) Page 30, Section 3.3: The assumption here seems to be that stream flow in relation to rainfall is a function of runoff and does not consider the hydrologic connection between rainfall, vegetation, aquifers and groundwater outflows to rivers and streams (baseflows). Please describe to what extent stream flow gains and losses to and from groundwater aquifers are considered in WAM data and analyses.

WAM simulated results were not analyzed to assess historical rainfall/runoff relationships in the upper basin because the WAM model simulates a hypothetical condition, as prescribed by the user, not the historical condition. However, streamflow gains and losses are effectively considered in the overall WAM process in two ways. First, the extent that historical streamflow gains and losses actually occurred are captured in the naturalized flows, the hydrologic input to the WAM model, because the naturalized flows are based on observed flows that reflect all historical gains and losses. Second, for most of the upper Colorado Basin, the WAM has channel losses associated with stream reaches between primary control points and these loss factors are applied to changes in flow due to water rights activities that are simulated in the WAM.

7) Page 30, Section 3.3: The studies cited by the report have indicated varying degrees of increased streamflow resulting from brush control projects. Additionally, in the San Saba River watershed it has been observed in Menard County that several creeks

that are dry streambeds all summer begin flowing surface water again in late October when mesquite has gone into dormancy, and the extensive clearing of juniper on the Blue Mountain ranch in Mason County has brought long-dead seeps and streams back to life. What is lacking is rigorous study and comparison of which species, upon elimination, yield the most improvement in streamflow.

a. In the Upper Colorado River basin there have been projects involving mesquite, juniper and salt cedar. There should be comparison studies among those species on effectiveness in improving flows, taking into consideration also:

i. the effect of varying degrees of density of the brush

ii. the effect of different soil types and terrain

iii. the effect of different post-removal practices

Agreed.

b. Page 30, Section 3.3.1: Please describe whether these feasibility studies cited include consideration of the hydrologic connection, and then specify the brush control practices that are required to re-establish the natural hydrologic cycle and re-establish baseflows to rivers and streams. Also, please mention if these studies include data collection and documentation, monitoring and quantifying impacts, or specify replanting with native prairie grasses or other restoration practices after brush removal.

The feasibility studies are typically based on water models that are calibrated to observed streamflow for some period of record, therefore they in effect consider hydrologic connections for the simulation period. There do not appear to be standardized requirements specifying what types of brush control practices are required to re-establish the natural hydrologic cycle, much less re-establish baseflows. As for data collection and monitoring, the North Concho Brush Control Project collected data and monitored surface and groundwater conditions for a period of 10 years after the project was complete and the results of this monitoring are summarized in the report in Section 3.3.2.1 and a detailed evapotranspiration analysis is described in Section 4.4. No other brush control project reviewed for this study appeared to have similar requirements placed on it and no specific requirements for replanting native grasses were noted. Review of the text of the current State Water Enhancement Plan lists compliance monitoring as one of the program goals but generally defines this as assurance that the "brush canopy is being maintained at 5% or less (target species only) of what was established after initial treatment during the 10-year contract". Furthermore, Section 203 of the Texas Agriculture Code contains the rules that apply to the Water Supply Enhancement Plan. Section 203.055 lists the approved methods for brush control that the TSWCB is to give consideration to and 203.055(5) lists one of the preferred methods of brush control as one that "will allow the revegetation of the area after the brush is removed with plants that are beneficial to stream flows, groundwater levels, and livestock and wildlife". The text of the report has been expanded to provide some additional details.

8) Page 30, Section 3.3.1: Please mention whether the Brush Control Program Act

specifies that the exact location, species of vegetation, and number of acres treated (mechanically or chemically) be documented, and that impacts on stream flow or water saved be quantified.

Section 203 of the Texas Agriculture Code contains the rules that apply to administering the Water Supply Enhancement Plan, the current name of the former Brush Control Act. Tract locations, targeted species, proposed number of acres treated, and projected water yield are all specified as required information to be included in the feasibility plans and is considered by the TSSWCB when evaluating feasibility plans. However, the impacts on flow or water savings after brush removal is accomplished has generally been based on information that was simulated as part of the approved feasibility study and then applied to the actual number of acres cleared. The text of the report has been expanded to provide some additional details.

9) Page 30, Section 3.3.1: The deep roots of prairie grass are the key to getting rainwater back into the soil to recharge the aquifer and restore baseflows (groundwater outflows that are a component of instream flows) to the surface waters before it runs off. The groundwater-surface water connection is a hydrologic system that needs to be maintained in "primed state" to effectively and efficiently pass water into the soil and thereby into the aquifer or alluvial baseflow. Management of this component in a brush control project is likely an essential aspect of restoring the hydrological system.

   a. Please mention whether the Brush Control Plan provides for re-planting of native prairie grasses or other restoration practices after brush removal.

Section 203 of the Texas Agriculture Code does not specifically require native prairie grass be replanted. See response to comment #7b above for more information.

10) Page 30, Section 3.3.1: Please mention whether HB 1808 addressed any deficiencies in data collection and documentation, monitoring and quantifying impacts, or whether it specified replanting with native prairie grasses or other restoration practices after brush removal.

It is beyond the budget and scope of this project to analyze all of the detailed aspects of Brush Control rules that HB 1808 changed from those enacted under previous Brush Control legislation. With regard to the prairie grass question, see response to comment # 9a above.

11) Page 31, Section 3.3.2.1, 2nd paragraph, 5th line: replace "motoring" with "monitoring."

Correction made.

12) Page 32, Section 3.3.2.3: There being no documentation from such a significant project is available from a project that has been ongoing for nearly 16 years is a deficiency that needs correction. Please mention whether monitoring of impacts was

included in the feasibility assessment or the project proposal.

No, monitoring of impacts of brush control was not addressed in this project's feasibility assessment.

13) Page 32, Section 3.3.2.4: Please specify whether this project includes monitoring for impact on stream flow.

No, monitoring of impacts of brush control was not addressed in this project's feasibility assessment.

14) Page 32, Section 3.3.3, next-to-last sentence: The term "invasive brush varieties" is used here. It is unclear if that term is intended to refer to Ashe juniper and mesquite, which are referenced earlier in the paragraph, or to a broader suite of species. Clarification would be helpful.

Agreed. Narrowed text in report to specifically refer to ash juniper and mesquite.

15) Page 37, Section 3.5: Bringing groundwater management into the overall water management practices in the upper basin might be an important aspect of future adaptive management of these natural systems and associated resources. Groundwater trends seem to vary throughout the study area. Groundwater management practices used by Groundwater Conservation Districts (instilled in their Management Plans) and by Groundwater Management Areas in developing their Desired Future Conditions might be diminishing groundwater outflows to rivers, streams, and springs, thus impacting baseflows.

   a. It would be useful to review the GMA DFCs and GCD Management Plans to determine which are protective of surface water and spring flow and which are not.

Agree with comment. With regard to recommendation in item (a), review of the ground water districts' desired future condition information is beyond this project's scope of work and budget.

16) Page 37, Section 3.5.1, last sentence of 1st bullet point: The reference to about 50% of the wells since 1960 being drilled in the Beal's Creek subwatershed is a very interesting one. If a conclusion can be drawn about the significance, or potential significance, of those wells to surface flow, it would be a helpful addition.

The majority of the new wells in Beal's Creek watershed were drilled for energy production purposes. The report text has been changed to reflect this.

17) Page 39, Section 3.5.4: It would be useful to have these springs and their associated aquifers shown in a figure similar to Figure 1A.

Figure 1A now includes the location of the 10 springs described in the report.

18) Page 39, Section 3.5.4: Dove Creek near San Angelo, Ft. McKratt springs near

Menard, San Saba Spring, and Seven Hundred Springs showed significantly increased spring flow during the '70's and late '80's and early '90's with significant declines to current levels thereafter. This should be noted in the report.

<u>The report text has been changed to make this clearer.</u>

19) Page 43, Section 3.9: Under new efforts to track soil moisture, it would be good to mention modelled soil moisture fields from 1979 to the present available from the National Land Data Assimilation System (NLDAS).

<u>The report text has been changed to add this additional source of information.</u>

20) Page 44, Section 4: This chapter could be made Chapter 2 so that it follows right after Project Overview. Having the literature reviewed come before the chapters presenting results would improve the flow of the report.

<u>Moving Chapter 4 to immediately after project overview would appear to describe several complex findings and analyses before the reader has the benefit of understanding the problem that the current Chapter 2 describes. No change was made to the order of the Chapters in the report.</u>

21) Page 47, Section 4.5: Please provide a summary of this section to highlight how information from the literature reviewed relates to the key results of the report.

<u>The text included in the draft report is considered to be sufficient.</u>

22) Page 48, Section 4.6: This scenario demonstrates the importance of the hydrologic connection between rainfall, the importance of woody vegetation returning water to the soil, aquifer recovery, and improved groundwater outflow (baseflow) to surface waters. All of these are components of hydrologic recovery. Please mention whether there was there a native prairie grass recovery component that went along with the woody plants.

<u>This comment is not clear, but it appears to ask whether the particular document summarized in this section describes a native prairie grass recovery component along with the increase in woody plants in the North Concho watershed during the period after 1960. Additional review of this document indicates that it does attribute "greater vegetation cover – both woody and herbaceous plants" to the hydrologic recovery but does not describe whether there was a deliberate replanting of native prairie grass or not. The text included in the draft report is considered to be sufficient.</u>

23) Page 53, Section 5.2.3: Please state which Groundwater Management Area and Groundwater Conservation District this is in and mention what the Desired Future Conditions and Management Plans are based on.

<u>The review of Groundwater Management Area's planning information, including their Desired Future Condition, is beyond this project's scope of work and budget.</u>

24) Page 53, Section 5.2.3: Please specify whether these groundwater declines were incorporated into WAM data. Please discuss whether such incorporation would have enabled an assessment of whether surface water availability was being significantly impacted.

As addressed in item #6 above, the WAM model configuration or simulated flows were not needed or reviewed to assess historical rainfall/runoff relationships in the upper basin. However, the response to item #6 does provide some insight to this question.

25) Page 53, Section 5.2.3, footnote[3]: Likely should be a reference to "Aquifers **of** Texas." See also footnote[4] on p. 54.

Correction made.

26) Page 54, Section 5.3.1: The following publications referenced in INTERA's Draft Report on GAM Improvements may provide some insight into the groundwater-surface water interactions in the upper basin and how they may have impacted runoff during some portion of the study period. These studies should be reviewed and included in the report if appropriate. INTERA may be able to provide other references and insights regarding aquifer conditions and outflows to surface waters.

- Slade, R.M., Jr., and Buszka, P.M., 1994, Characteristics of streams and aquifers and processes affecting the salinity of water in the upper Colorado River Basin, Texas: USGS, Water Resource Investigations Report 94-4036.
  - **See Section 4.3.1, page 34 in GAM Improvements Draft Report**
- Slade, R.M., Jr., Bentley, J.T., and Michaud D., 2002. Results of Streamflow Gain-Loss Studies in Texas, With Emphasis on Gains From and Losses to Major and Minor Aquifers, Texas, 2000, U.S. Geological Survey - Open-File Report 02-068.
  - **See Figure 4-2 and 4-3 in GAM Improvements Draft Report**
- Wolock, D.M., 2003b, Hydrologic landscape regions of the United States raster digital data U.S. Geological Survey Open-File Report 03-145 and digital data set (available at http://water.usgs.gov/lookup/getspatial?hlrus).
  - **See Figure 4-9 in GMA Improvements Draft Report**
- Wolock, D.M., and others, 2003a, Flow characteristics at the US Geological Survey steam gages in conterminous United States: US Geological Survey Open-File Report 03-146, Data accessed February 2016, Available from: (available at http://water.usgs.gov/lookup/getspatial?qsitesdd).
  - **See Figure 4-7, 4-8 and 4-9 in GMA Improvements Draft Report**
- Wolock, D.M., and others, 2004, Delineation and Evaluation of Hydrologic-Landscape Regions in the United States Using Geographic Information System

Tools and Multivariate Statistical Analysis: Environmental Management, Volume 34, Supplement 1, pp. 71-88.

– **See Figure 4-9 in GMA Improvements Draft Report**

As a result of this comment, each of the references stated above was reviewed. For various reasons, the text of the report was not changed in response to these documents/data sources.

27) Page 58, Section 5.3.2, sentence beginning on 5th line of first paragraph on this page: It is unclear if there is something about similar precipitation patterns or other similarities that make the two referenced periods particularly appropriate for comparison. Please clarify.

This comment was simply a general observation that there were similarities between the early and late periods of record between study site #1 and study site #5, with no specific connection inferred.

28) Page 64, Section 5.7, final sentence: It would be helpful to have an additional sentence explaining the implications of what is now the final sentence. It appears that this may mean that the reservoirs on the Beal's Creek watershed are not the cause of the downward trend at the referenced study sites. This could be stated more explicitly.

The text has been modified for clarity.

29) Page 65, Section 6.1, page 65: Please explain whether this implies that these segments are over-allocated.

The term "over-allocated" suggests that more water has been authorized for use in these segments than what these segments should have been authorized, which is a complicated concept and not within the scope of work for this project to determine. However, as stated in the report in section 6.2.2, most of these segments are recognized as being very limited with regard to water being available for appropriation for new users, which means these segments are fully allocated. No change in the report text was made.

30) Page 65, Section 6.1: second-to-last sentence in section: Delete "a" in the sentence: "However, for ~~"a"~~ several of the study sites..."

Correction made.

31) Page 68, Section 6.3: It is unclear whether the report conclusion is intended to indicate that there is "nothing to see here" with respect to declining flows, because it was all likely caused by a dry period, or that it remains an open question about the cause. Although, it seems unsurprising that an unusually wet period would result in increased flows, it is not clear what the conclusion section is intended to suggest about the implications for longer-term trends.

a. It would be helpful if more discussion could be included in the conclusion to state what if observed trends at the study site have any obvious implications for longer-term trends or if the results show a mixed signal that preempts any firm conclusion from being drawn on longer-term trends.

The first paragraph of Section 6.3 has been modified to more clearly summarize the fact that several of the study sites show a problem in that declines in observed flows over time cannot be explained by historical rainfall quantities or water uses by existing appropriative water rights and that the other activities which are believed to contribute to these declines do not have sufficient information available to make quantifiable conclusions. No obvious implications or projections could be made with regard to longer-term trends with the information currently available.

Figures and Tables Comments:

1) Figure 1A, page 3:

   a. It would be helpful in evaluating the spring and aquifer data if a map were included in the main report that identifies the location of the springs evaluated and the location of aquifers underlying those springs.

Pursuant to an earlier comment, Figure 1A has been modified to show the locations of the springs discussed in Section 3.5.4.

   b. Please indicate whether the subwatersheds shown in Figure 1A correspond to a particular Hydrological Unit Code (HUC) level.

The subwatersheds shown in Figure 1A do not precisely correspond to any HUC. Instead, these subwatersheds correspond to the locations of streamflow gages that were used in the TCEQ Colorado WAM and were adopted in this study for the reasons stated in Section 1.5.

2) Figure 2, p. 11: It would be helpful to add the dashed line (---) to the legend. It is explained in the accompanying text as representing the trend line.

Correction made.

3) Figure 3, p. 13: It would be helpful to add the dashed lines (---) to the legend. They are explained in the accompanying text as representing the trend line.

Correction made.

4) Table 13, page 38: It should be noted that study areas 7, 8, 12, and 13 are not included in this table and therefore are presumed to have stable or increasing groundwater elevations.

The text has been altered to clarify this.

5) Table 14, page 39: The Report does not note (1) which aquifers are associated with each spring, (2) which aquifers have declining, steady, or increasing elevations, and (3) what groundwater management practices (DFCs and GCD Management Plans) are associated with each spring/aquifer. This would be very useful information to include in the table.

(1) The text has been modified to state which aquifer is associated with each spring.
(2) Appendix K contains the requested information for the aquifers in the study areas that had monitoring wells associated and which had enough observations to be able to make a general determination.
(3) The review of Groundwater Conservation District Management Plans and Desired Future Condition planning information is beyond this project's scope of work and budget.

6) Figure 7, p. 40: It would be helpful to add the dashed lines (---) to the legend. They are explained in the accompanying text as representing the trend line.

Correction made.