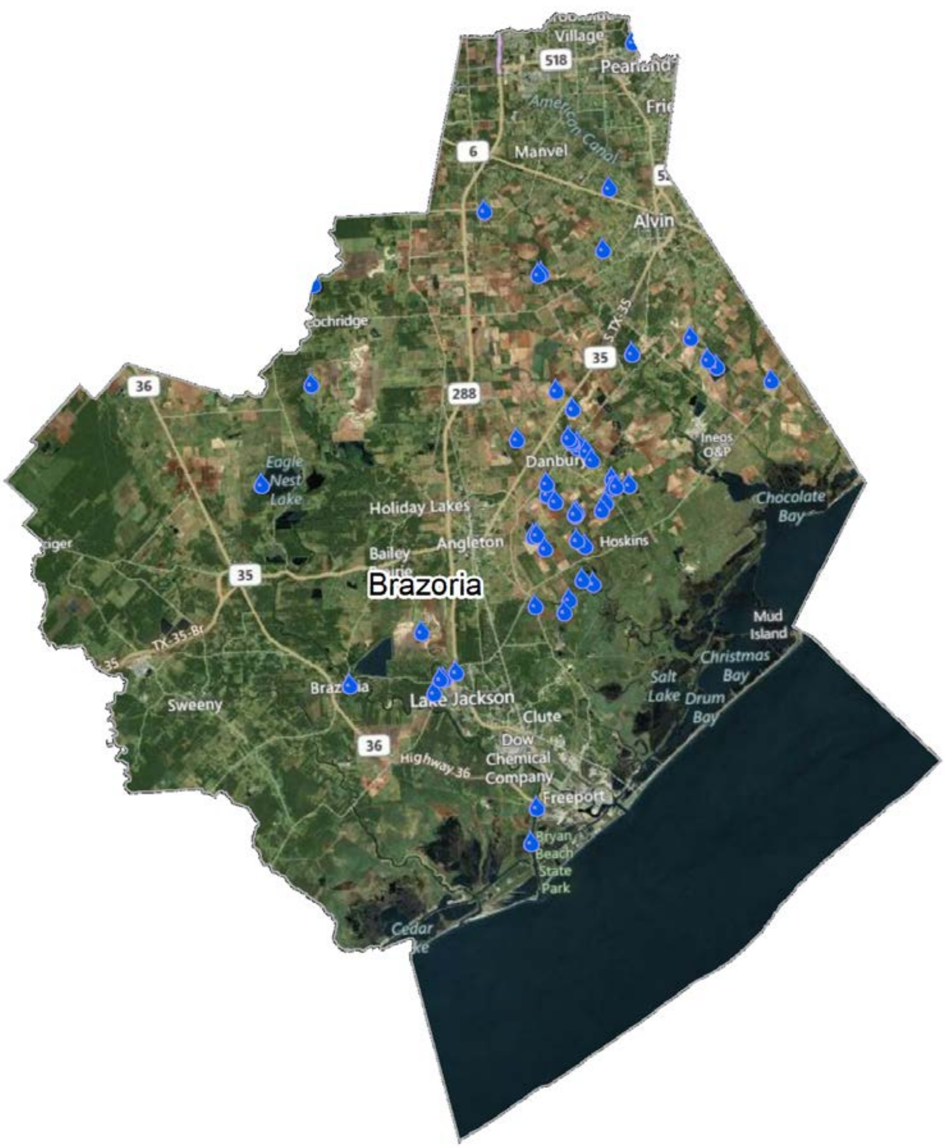
APPENDIX B

Water Availability and Reliability for Brazosport Water Authority Report by INTERA

December 2013

CDM Smith

Water Availability and Reliability for Brazosport Water Authority



Final Report
December 2012

INTERA
Geosciences & Engineering

Contents

Executive Summary

A detailed review was performed of water availability and quality in the Brazos Alluvium and the Gulf Coast Aquifers. The assessment indicates that the Brazos alluvium would likely not be a good candidate for a long-term water supply source. However, our studies identify the lower portion of the Chicot Aquifer and upper portion of the Evangeline Aquifer as a viable long-term water supply sources for brackish water. Analyses indicate that properly designed wells screened at depths below 600 feet near the Brazosport water treatment plant location will produce brackish water at rates between 900 gpm (~550 AFY) and 2,000 gpm (~1,200 AFY). The water quality of pumped water from the slightly saline aquifer zone will vary locally but the TDS measurements of the produced water should likely be between 1,500 and 2,000 ppm. Within a 15 miles radius of the water treatment plant, there are several salt domes that cause local degradation of water quality. As a result, production wells should not be located close to these salt domes.

A comprehensive review of surface water availability was also performed. Results from the analysis of the monthly Water Availability Models (WAMs) for water in the Brazos Basin shows that the Brazosport Water Authority water right has a reliability of approximately 90.5 percent for the WAM period of record (1940 – 1998). Reliability improves only slightly when the diversion amount is reduced from full authorization (45,000 ac-ft per year). The analysis demonstrates that during times of drought, either there is water available for diversion, or there isn't.

In 2011, the Brazos River experienced the worst single year drought on record. Unfortunately, data from this drought are not contained in the state's WAM for the Brazos. As part of this contact, though not explicitly stated in the scope of work, INTERA also analyzed daily flows in the Lower Brazos. Based on INTERA's Daily-Hydro model, the Brazosport Water Authority could have diverted 16,707 acre-ft/yr in 2011. Should the Brazosport Water Authority have access to water stored in the "Planned Reservoir" under consideration by Dow, then they could expect to divert 22,661 acre-ft/yr under a repeat of the drought conditions experienced in 2011. These diversion amounts assumed BWA attempted to divert its full annual permitted quantity.

Analysis of Brazos River flow and salinity data indicates that when the streamgage near the Dow Pump station reads 600 cfs or below, salinity *will* be above the TCEQ/EPA drinking water standard. These low flows occur less than ten percent of the time in the period of record. Between 600 and 2,100 cfs, there is a possibility that salinity standards will be exceeded, depending on tides and other factors. When the flow at the Dow Pump station is above 1,750 cfs, the TCEQ drinking water standard (TDS < 1,000 mg/L) is always met and above 2,100 cfs the EPA standard (TDS < 500 mg/L) for drinking water is also met. These flow levels occur 63.0 and 57.9 percent of the time, respectively. There is some indication that the salinity situation is worsening in the Lower Brazos – which makes sense given the increased use of water in the basin – however analyses found that the trend is not statistically significant.

Introduction

On June 4, 2012 CDM Smith Inc. and INTERA, Inc. (INTERA) entered into contract to perform the following professional services:

Task 1.1: Assessment of Groundwater Availability in the Brazos Alluvium
Task 1.2: Assessment of Groundwater Availability in the Gulf Coast Aquifer
Task 2.1: Assessment of Surface Water Reliability in Brazoria County
Task 2.2: Assess Salinity as an Impediment to Surface Water Availability

A final task was dedicated to reporting and presentation of the results.

1.1 Groundwater Availability in the Brazos Alluvium

The boundaries assigned to the Brazos River Alluvium Aquifer by the TWDB do not extend into Brazoria County. For this project the Brazos alluvium is delineated by the Geological Atlas of Texas (GAT) sheet (Barnes, 1992). The Brazos alluvium consists primarily of fine sand with some clay near the surface and with coarse sands and gravel near its base. In the southwest portion of the study area, the Brazos Alluvium merges with Colorado alluvium. Production in the Brazos alluvium is expected to be variable with regard to flow rate and water quality. The primary factor that affects the flow rate and water quality is lateral continuity of the sand deposits intersected by the well screen.

The primary source of hydrogeologic data for the Brazos alluvium is information on the lower reaches of the Brazos River Alluvium Aquifer described by Cronin and Wilson (1967) and Shah and Houston (2010). Most of the Brazos alluvium in the study area is estimated to have thicknesses between 30 to 70 feet and to have transmissivities between 500 and 3,000 ft^2/day. In areas where alluvium sands are well connected, transmissivity values greater than 6,000 ft^2/day may occur.

Figures 1.1 and 1.2 show the locations of wells in the study area with at least one measurement of Total Dissolved Solids (TDS) and meeting specific criteria discussed below. Each well is labeled with the average of its measured TDS concentrations. The well information was extracted from the Texas Water Development Board Groundwater Database. TDS typically can be correlated to well or well screen depth. Figure 1.1 shows wells with average TDS concentrations less than 1,000 ppm and includes the depth of the well. A TDS concentration of 1,000 ppm is the criteria used by the TWDB classify groundwater as fresh water. Figure 1.2 shows wells with average TDS concentrations above 1,000 ppm and includes the depth of the well. The TWDB defines brackish water by TDS concentration of the water between 1,000 and 10,000 ppm. Based on the few wells with well depths less than 100 feet shown in Figures 1.1 and 1.2 and the TDS information presented by Shah and Houston (2010), groundwater in the Brazos alluvium is estimated to have an average TDS concentration of about 900 mg/l and to vary between 600 and 1,500 ppm.

Within a few miles of the water treatment plant there are areas where wells fully penetrating the alluvium will be capable of producing 150 to 250 gpm. Within 10 miles of the plant, wells that intersect well-connected river channel deposits may be able to produce up to 600 gpm. A primary concern with an alluvial well is long-term production because of the potential for water-quality degradation. Potential causes of water quality degradation in these wells include; exposure to surface contamination sources, relatively short travel times from a groundwater source to the well, and the possibility of significant changes in flow patterns during times of drought.

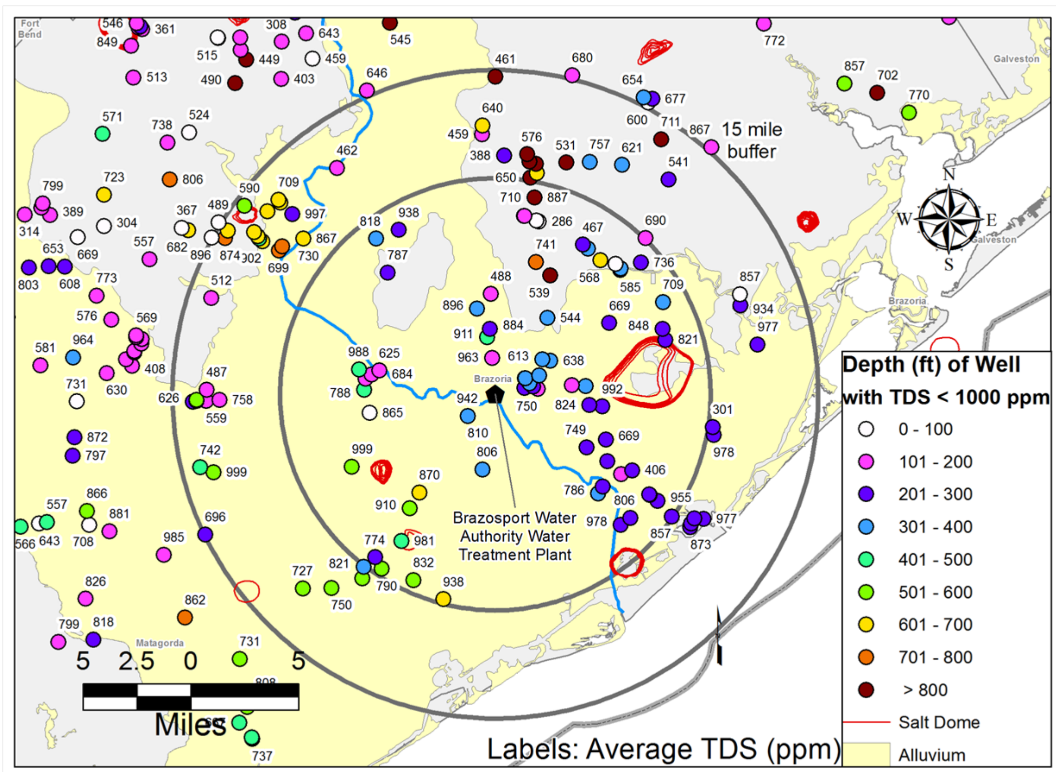


Figure 1.1 - Wells with measured average TDS concentrations below 1,000 ppm.

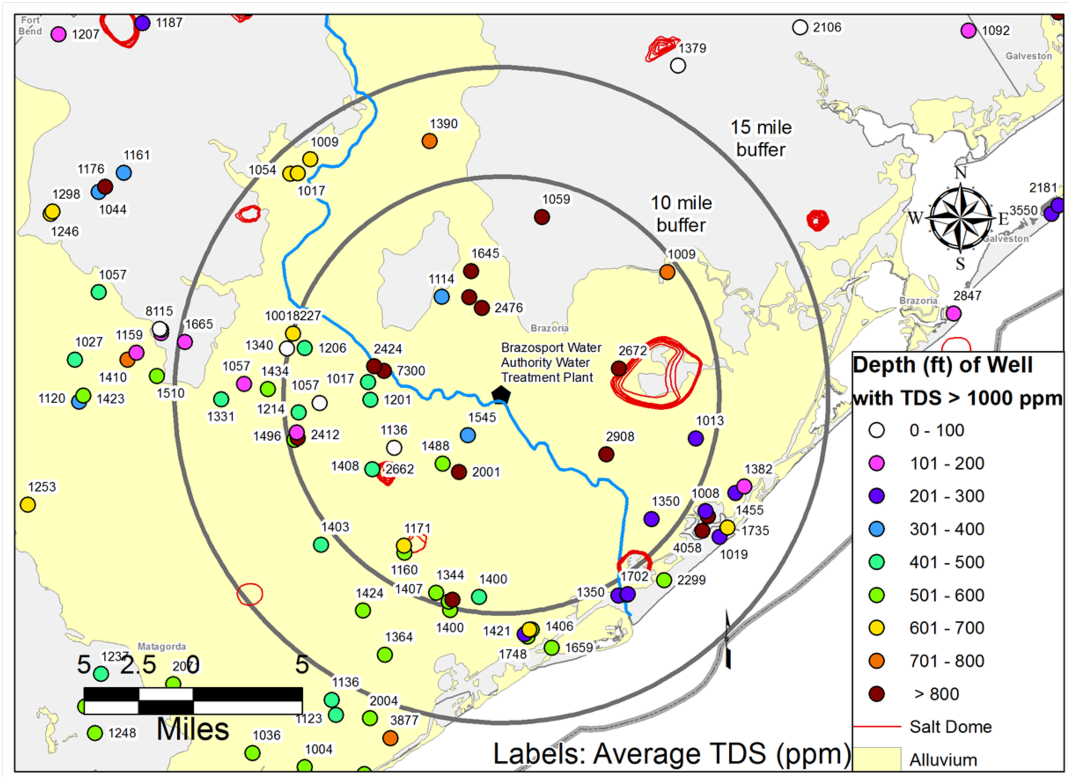


Figure 1.2 - Wells with measured average TDS concentrations above 1,000 ppm.

1.2 Groundwater Availability in the Gulf Coast Aquifer

The stratigraphy of the Gulf Coast Aquifer System and the thickness for the Chicot Aquifer and the underlying Evangeline Aquifer are defined by the Texas Water Development Board's most recent studies of the Gulf Coast Aquifer stratigraphy (Young, 2010, 2012). As discussed in Section 1.1, the mapped concentrations of Total Dissolved Solids (TDS) were developed using data extracted from the Texas Water Development Board Groundwater Database.

For wells less than 800 feet deep, the measured TDS concentrations vary several hundred parts per million (ppm) within distances of less than a few miles. Among the causes for these variations are the presence of salt domes, former brine pits used by the oil and gas industry, upward leakage of brines through faults, and differences in mineralogy and groundwater flow in the Gulf Coast Aquifer sediments. Based on these TDS measurements and estimates of TDS based on the analysis of geophysical logs, the Texas Railroad Commission has mapped the base of Superior water and Useable water in the Chicot Aquifer (Figures 1.3 and 1.4).

In Brazoria County, the Texas Railroad Commission defines Superior and Useable water quality by TDS concentrations less than 1,000 ppm and 3,000 ppm, respectively. Figures 1.3 and 1.4 illustrate that the base of the Superior (or fresh) water occurs primarily at depths between 250 to 600 feet below ground surface and that the base of Useable (or slightly saline) water occurs primarily at depths of about 800 to 1000 feet below ground surface. As can be seen in Figure

1.4, the depth to the base of Useable water is shallower in the proximity of some salt domes. At these locations the salt dome is close enough to the surface that dissolution of minerals from the salt domes affects the TDS concentrations in the groundwater intersected by the wells. Figures 1.5 and 1.6 show the percentage of the Chicot Aquifer and the thickness of the Chicot Aquifer that is brackish, respectively (brackish groundwater is defined as groundwater with TDS greater than 1,000 ppm). The information in these figures show that across most of the study area, more than 60 percent of Chicot Aquifer is brackish and that this percentage typically represents more than 1,000 feet of the aquifer.

The slightly saline portion (TDS between 1,000 and 3,000 ppm) of the Gulf Coast Aquifer System includes the brackish portion of the Chicot Aquifer and a portion of the upper-Evangeline Aquifer. Figures 1.7 and 1.8 show estimated transmissivity values for the fresh and slightly-saline portion of the Gulf Coast Aquifer System based on the hydrogeological parameters in the groundwater flow model developed for the Lower Colorado River Authority for the Gulf Coast Aquifer (Young and others, 2009). The figures show, that at most locations, the transmissivity of the fresh water aquifer zone is more than two times greater than the transmissivity of the slightly saline aquifer zone. Nonetheless, the slightly saline aquifer zone has sufficient transmissivity to serve as a water supply. In the vicinity of the Brazosport water treatment plant, the transmissivity of slightly saline aquifer zone averages about 4,000 to 5,000 ft^2/day (Figure 1.8). Based on a transmissivity of 4,500 ft^2/day in the vicinity of the Brazosport water treatment plant, a reasonable production rate for a well intersecting the slightly saline aquifer zone is between 900 gpm (~550 AFY) and 2,000 gpm (~1,200 AFY). Thus, development of a water supply of 3,000 to 10,000 AFY should be achievable using a network of 6 to 10 wells.
Figure 1.8 suggests that the transmissivity in the slightly saline portion of the aquifer is generally lower downdip and southwest of the Brazos River as compared to updip and northwest of the Brazos River at the location of the Brazosport water treatment plant. The data found in Figures 1.9 and 1.10 add additional support to this conclusion. Figures 1.9 and 1.10 show the estimated percentage and thickness of sand in the slightly saline aquifer zone, respectively. These sand maps are based on an analysis of the geophysical logs from analyses performed as part of this study and from Young and others (2010, 2012). The results from Figures 1.8, 1.9, and 1.10 suggest that properly designed wells screened at depths below 600 feet near the Brazosport water treatment plant should produce brackish water at rates between 900 gpm (~550 AFY) and 2,000 gpm (~1,200 AFY).

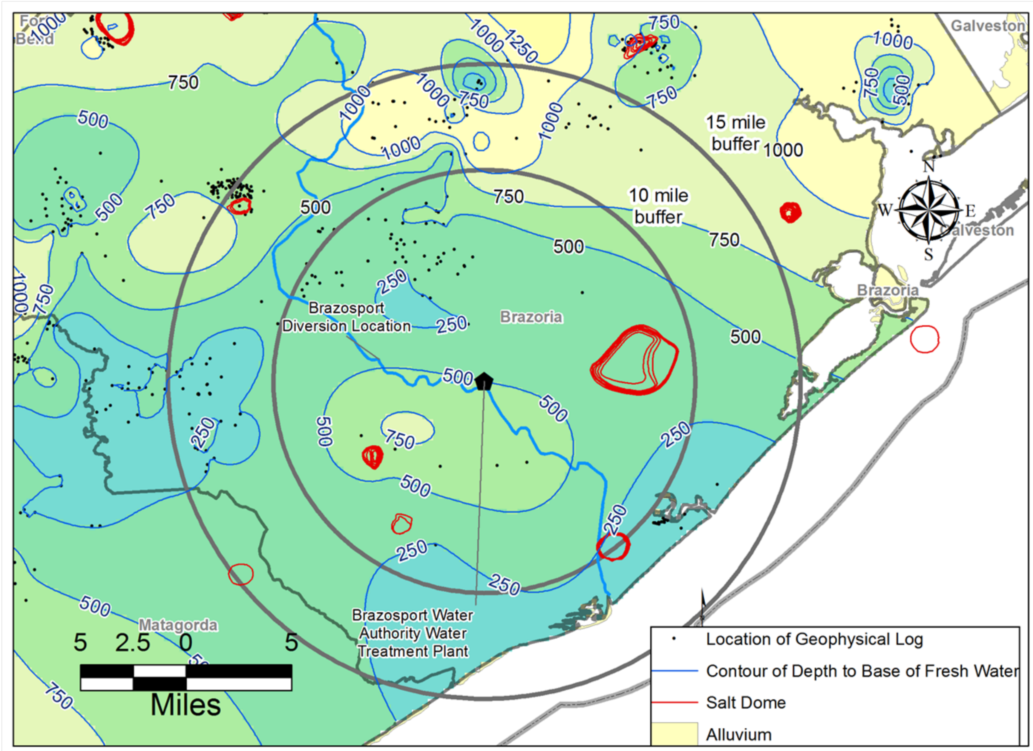


Figure 1.3 - Depth to the Base of Superior Water based on the Texas Railroad Commission estimates of TDS concentration from analysis of geophysical logs.

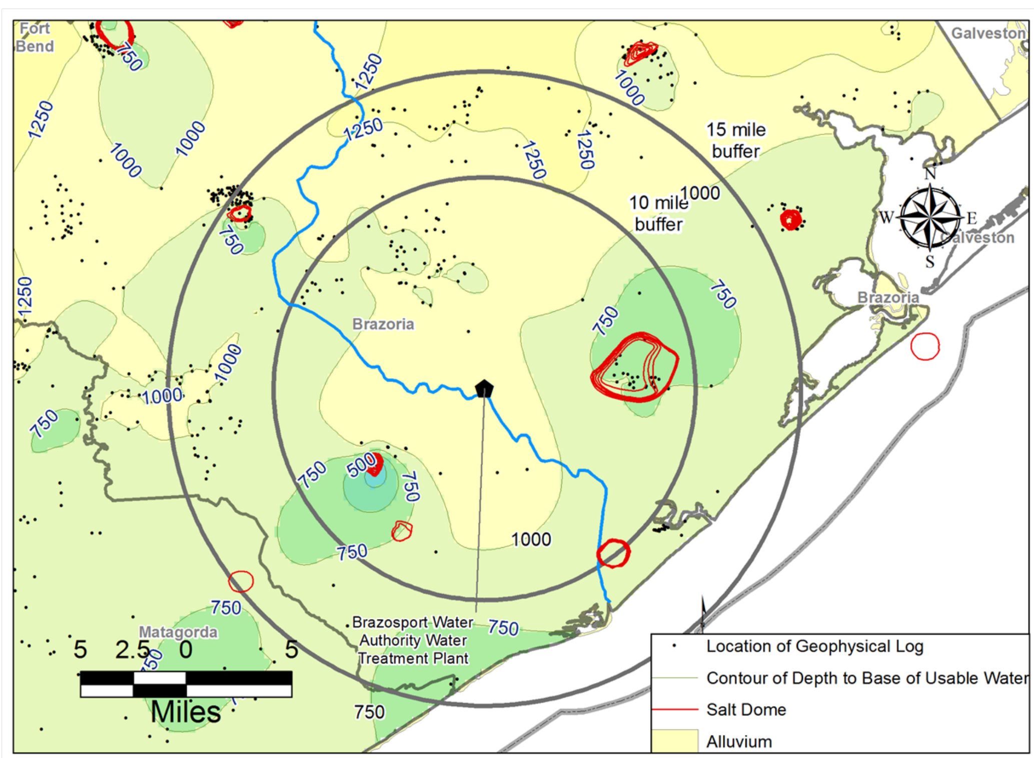


Figure 1.4 - Depth to the base of Useable Water based on the Texas Railroad Commission estimates of TDS concentration from analysis of geophysical logs.

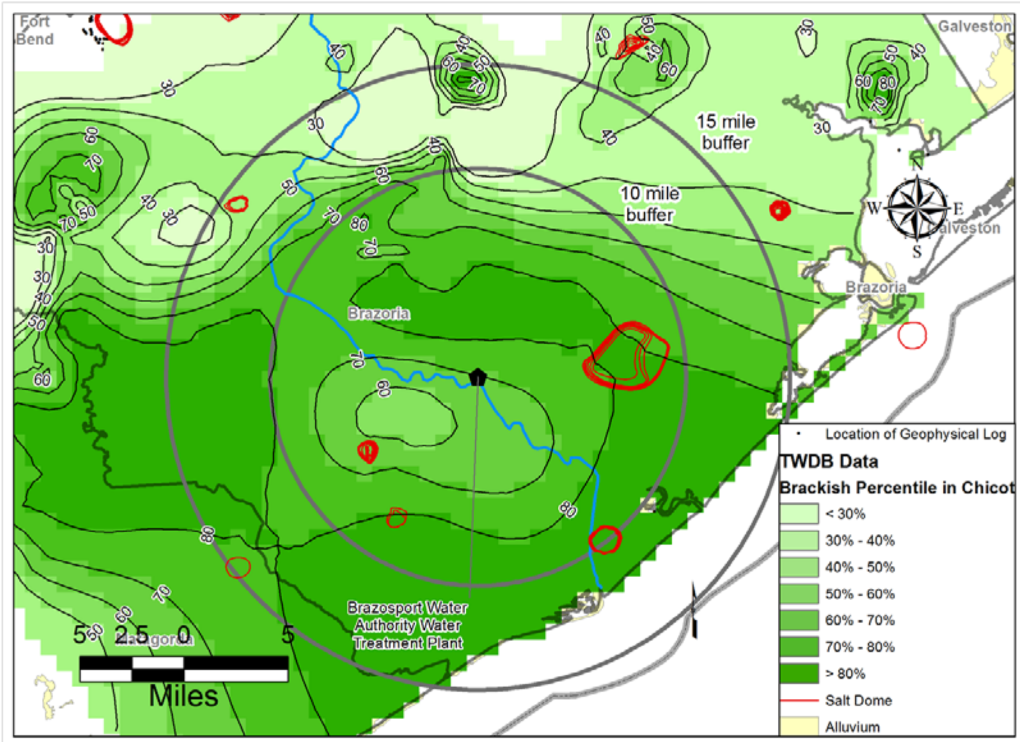


Figure 1.5 - Percentage of the Chicot Aquifer below the base of fresh water shown in Figure 1.3 and considered brackish water with a TDS concentration greater than 1,000 ppm.

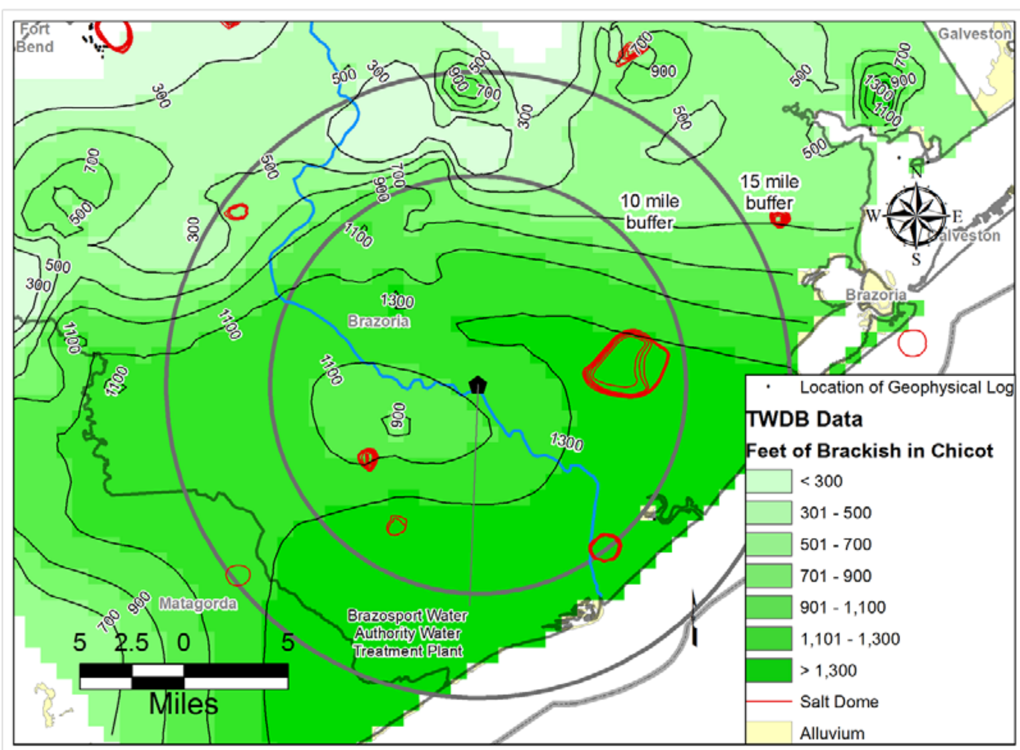


Figure 1.6 - The thickness (ft) of the Chicot Aquifer below the base of fresh water shown in Figure 1.3 and considered brackish water with a TDS concentration greater than 1,000 ppm.

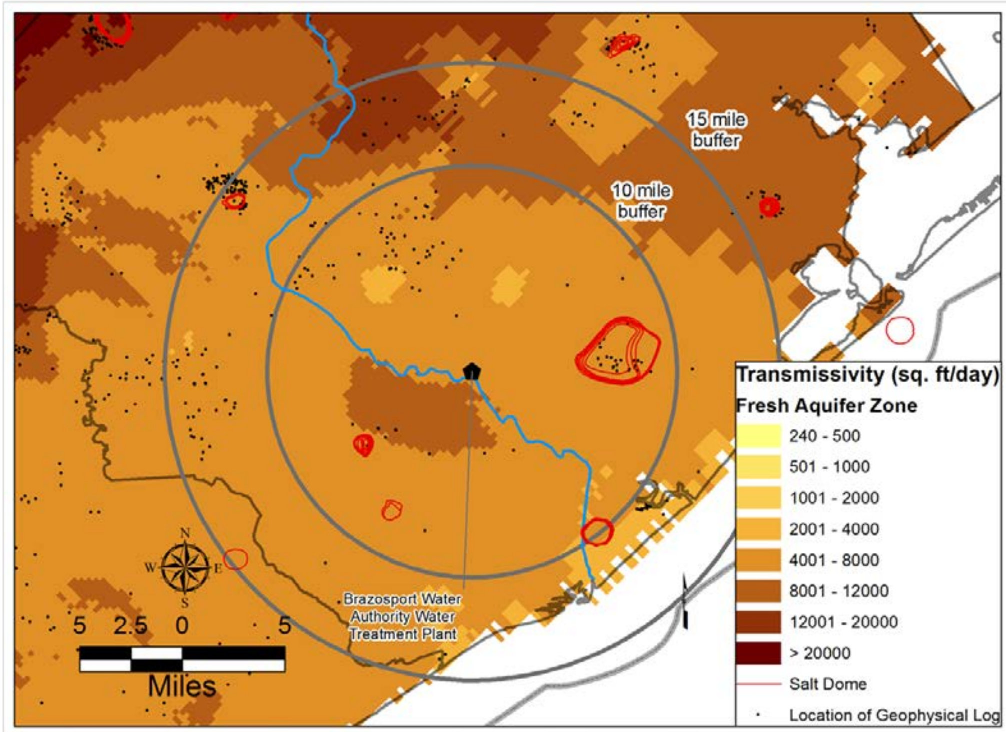


Figure 1.7 - Transmissivity estimates for the fresh aquifer zone based on the aquifer parameters in the Lower Colorado River Basin Model (Young and others, 2009) developed by the LCRA.

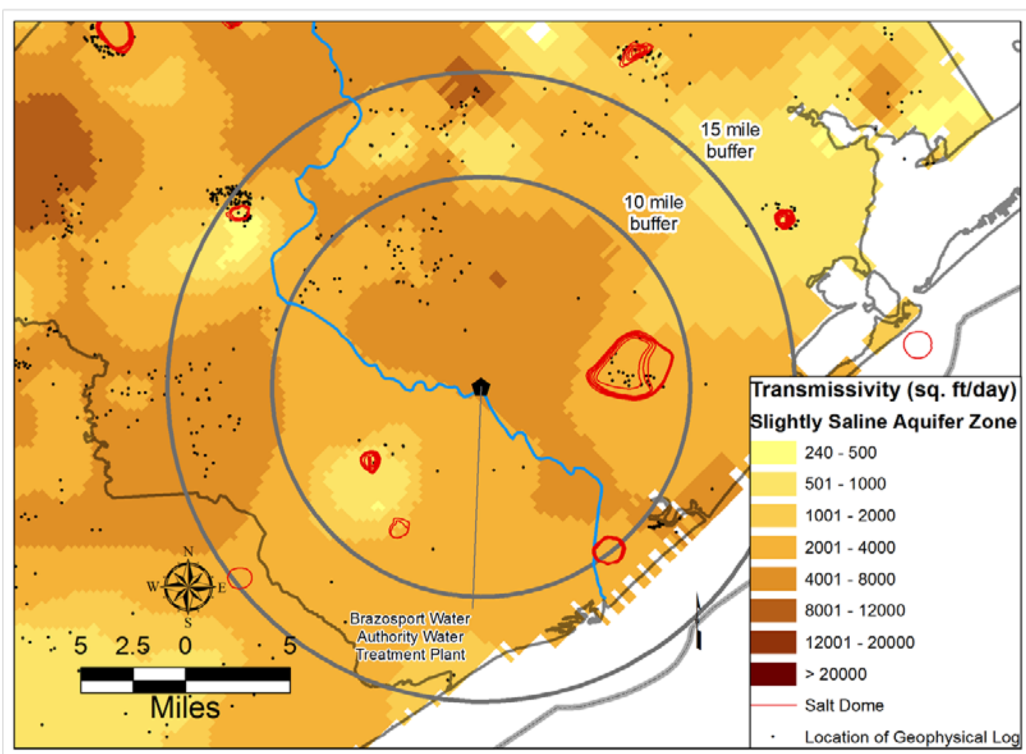


Figure 1.8 - Transmissivity estimates for the brackish aquifer zone based on the aquifer parameters in the Lower Colorado River Basin Model developed by the LCRA.

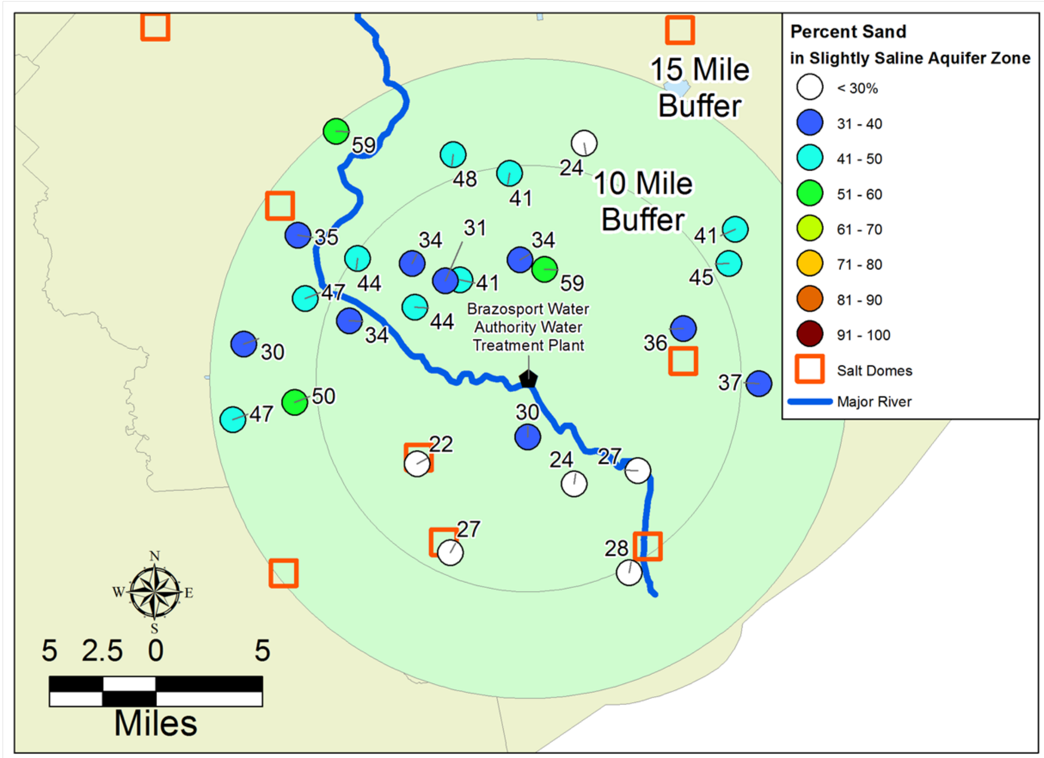


Figure 1.9 - Percentage of sand in the slightly saline (TDS between 1,000 ppm and 3,000 ppm) portion of Chicot and Evangeline Aquifers in the study area.

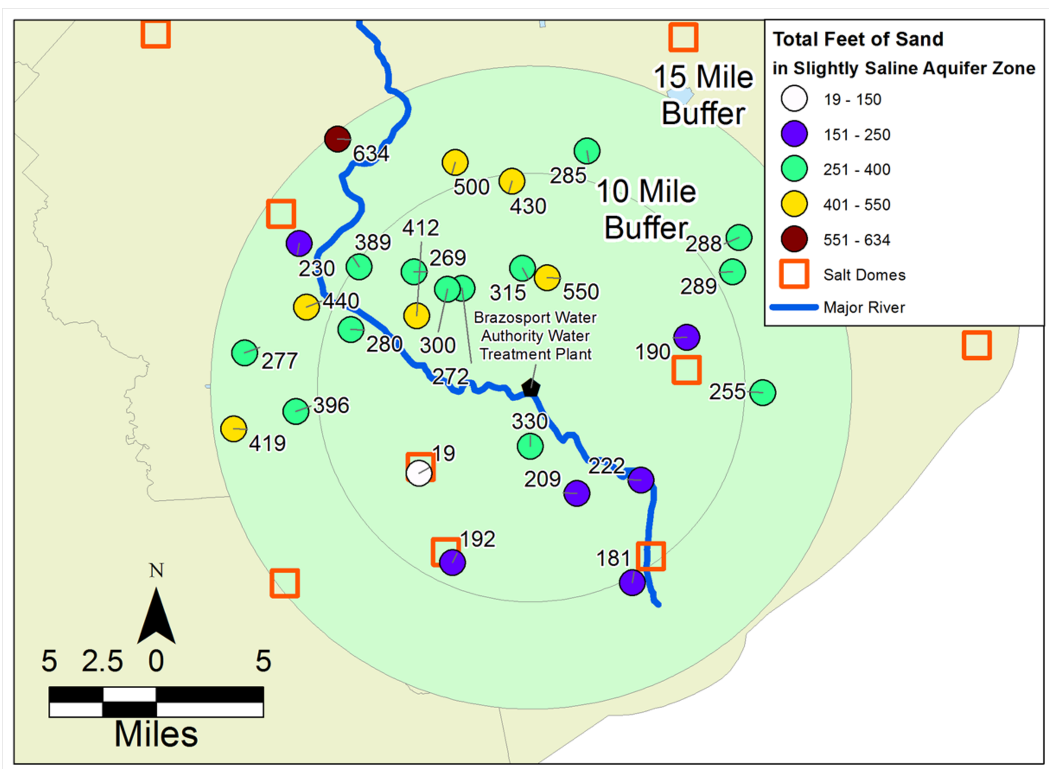


Figure 1.10 - Thickness (ft) of sand in the slightly saline (TDS between 1,000 ppm and 3,000 ppm) portion of Chicot and Evangeline Aquifers in the study area.

2.1 Surface Water Reliability

This section discusses the assessment of surface water reliability for all of the water rights in Brazoria County. The Water Rights Analysis Package (WRAP) Modeling System was used with the Texas Commission on Environmental Quality's (TCEQ) Water Availability Model (WAM) for the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Tables were generated containing monthly modeled diversions and targeted diversions for the modeled period from 1940 through 1997. Scripts were then used to assess both the reliability and the maximum number of consecutive months when diversions were less than their targets for each of the water rights in Brazoria County.

2.1.1 WRAP Modeling

Water rights in Brazoria County were modeled using the Water Rights Analysis Package (WRAP) Modeling System, July 2010 version. The Full Authorization (bwam3) Brazos River Basin and San Jacinto-Brazos Coastal Basin Water Availability Model (WAM) input files for WRAP were downloaded from the Texas Commission on Environmental Quality's (TCEQ) website (TCEQ, 2012). One slight modification was made to the bwam3 model to incorporate monthly water use coefficients given to INTERA by the Brazosport Water Authority (BWA). This distribution is provided below, in Table 2.1. Once this modification was completed, the model was then run in WRAP SIM and output generated. The next step was to use the TABLES program included in WRAP to output monthly time-series of targets and diversions for each water right. Table 2.2 lists the non-zero water rights that were identified in Brazoria County. In WRAP, some water rights are modeled having diversions at different locations or "control points". The location of each control point can be seen in Figure 2.1.

Table 2.1 Brazosport Monthly Water Use Coefficients.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.00	0.95	0.91	0.95	0.90	1.00	1.01	1.06	1.09	1.09	1.06	0.98

Table 2.2 Brazoria County Water Rights identified in bwam3 WAM.

Water Right Holder [1]	Priority Date	Diversion Amount (AFY)	Source(s)	Control Point(s)
THE RANDOLPH CO. ET AL	6/16/1914	3620	AUSTIN BAYOU	535244
ALBERT KUCHAR	6/25/1914	683	AUSTIN BAYOU	534701
CLEVELAND DAVIS III ET AL	6/25/1914	454	AUSTIN BAYOU	534801
DONALD JOE BULANEK ET AL	6/25/1914	1107	FLORES BAYOU	534601
E C STOKLEY TRUSTEE	6/29/1914	400	BASTROP BAYOU	534241
TOM TIGNER TRUST	6/30/1914	600	BASTROP BAYOU	534111
DONALD JOE BULANEK ET AL	5/9/1923	566	FLORES BAYOU	534601
CHOCOLATE BAYOU WATER CO	8/3/1927	1500	CHOCOLATE	CON251
DOW CHEMICAL CO	2/28/1929	20000	BRAZOS RIVER	532802
C E ZWAHR ET AL	12/9/1936	506	AUSTIN BAYOU	534501
MRS W M GARRETT	12/31/1936	1482	AUSTIN BAYOU	534442
CHOCOLATE BAYOU WATER CO	9/21/1937	5000	CHOCOLATE	CON251
A FARRER ET AL	1/16/1940	600	AUSTIN BAYOU	535141

TEXAS DEPT OF CRIMINAL JUSTICE	4/24/1940	946	BRAZOS RIVER, OYSTER CRK	532701, 533811
CHOCOLATE BAYOU WATER CO	10/15/1940	4000	CHOCOLATE	535703
CHOCOLATE BAYOU WATER CO	4/9/1941	2000	CHOCOLATE	CON251
DOW CHEMICAL CO	2/14/1942	210000	BRAZOS RIVER, OYSTER CRK	532802, 532832
CHOCOLATE BAYOU WATER CO	3/31/1942	2000	CHOCOLATE	535702
R L ALEXANDER & M A CROUCH	12/31/1943	968	CLEAR CRK	536401
ALVIN GOLF & COUNTRY CLUB	12/31/1945	54	MUSTANG CRK	535901
BIERI FARM, INC.	3/22/1947	900	FLORES BAYOU	534931
T L SMITH TRUST ET AL	1/15/1948	1800	VARNERS CRK	549231
J W ISAACS	3/31/1948	560	COUNTY DITCH	535601
DOW CHEMICAL CO	4/3/1951	7500	Buffalo Camp Bayou	532831
R T MARSHALL TRUSTEE	3/31/1960	187	W FRK CHOCOLATE	535401
BRAZOSPORT WATER AUTHORITY	4/4/1960	45000	BRAZOS RIVER	536602
DOW CHEMICAL CO	4/4/1960	65020	BRAZOS RIVER	532802
JAMES SCOPEL	4/15/1962	160	DITCH MUSTANG	536001
BEVERLY T MCDONALD ETAL	3/30/1965	112	BRAZOS RIVER	532301
CHOCOLATE BAYOU WATER CO	3/14/1966	17000	CHOCOLATE	535741
JOHN R & J W ISAACS	11/15/1968	1200	CHOCOLATE	535501
A FARRER ETAL	4/9/1969	900	AUSTIN BAYOU	535141
TIGNER IRRIGATION CO.	3/1/1971	3000	NEW BRUSHY BAYOU	534341
DOW CHEMICAL CO	3/8/1976	3136	BRAZOS RIVER	532802
C E ZWAHR ET AL	7/12/1976	392	AUSTIN BAYOU	534501
CHOCOLATE BAYOU WATER CO	11/15/1976	26000	CHOCOLATE	535702, CON251
J V 3 INC	4/18/1983	360	AUSTIN BAYOU	P40101
DONALD JOE BULANEK ET AL	4/24/1984	1139.5	FLORES BAYOU	534642
GARRETT RANCH INC	5/8/1984	2000	AUSTIN BAYOU	420102
C F BROWN JR TRUSTEE	5/22/1984	657	FLORES BAYOU	413241
BIERI FARM, INC.	5/29/1984	600	FLORES BAYOU	534931, 534902
JOHN R & J W ISAACS	9/25/1984	800	CHOCOLATE	535501
RAYMOND LE COMPTE ET AL	10/30/1984	2925	KING CRK	421631
ANNA KOLANCY	1/3/1985	225	AUSTIN BAYOU	422141
TEXAS DEPT OF CRIMINAL JUSTICE	9/19/1985	100	OYSTER CRK	533841
REX C BAILEY JR ET AL	10/16/1985	2600	OLD BRUSHY	502341, 502302
TIGNER IRRIGATION CO.	5/9/1986	262	NEW BRUSHY BAYOU	534341
JOHN D VIEMAN ET AL	8/29/1989	979	AUSTIN BAYOU	525642
UNITED STATES DEPT OF ENERGY	7/14/2000	52000	BRAZOS RIVER	533201

(1) Information in this table was taken from TCEQ's bwam3 model.

Figure 2.1 – Location of Control Points in Brazoria County.

2.1.2 Post-Processing

The previous section discussed how WRAP was used to generate monthly diversion targets and water availability for each water right. The values from these outputs were used with scripts to ascertain the 1) reliability and 2) number of consecutive months at which diversions are not possible. Results were also evaluated over a range of diversion amounts (1-100% of the permitted diversion amount). Model post-processing was conducted in five steps, as follows:

1) Determine water available for diversion for each water right, by month.
2) Set diversion target for each water right and for a range of percentages (1-100%) of the permitted target amount.
3) Estimate maximum number of consecutive months with shortages for each water right and for each permitted target percentage (1-100%).
4) Determine reliability for each water right. Permitted target percentage (1-100%) was calculated based on the number of months where the target amount was greater than the water available divided by the total number of months simulated (i.e. 696 months).
5) Generate graphs and tables to summarize findings.

2.1.3 Results from the Analysis of the WAMs

The results for each of the water rights are presented in Tables 2.3 through 2.5. Table 2.3 lists the permitted monthly and annual diversion targets for each of the water rights. Table 2.4 presents the calculated reliability at each water right for various percentages of the permitted target amount. For example, Brazosport Water Authority's water right (priority date 4/4/1960) has a reliability of 90.5% for a target diversion equal to 100% of their permitted amount, and a 91.5% reliability when trying to divert only 1% of the permitted amount. In this example the reliability does not vary substantially (an increase of only 1%) because the model reports a few months where no diversions are possible and a substantial part of time the full diversion amount is available. Appendix C contains a graph for each water right showing the deficit between the target amount and the water available for diversion. Upon inspection of the Brazosport water right graph, the months where diversions were not possible can be seen. Most locations show little improvement in reliability with change in diversion amount. This is because in the model the permitted amount is either available in its entirety, or not at all for the months in the simulated time series. Table 2.5 presents the number of consecutive months for which diversions are not possible at each water right and for various percentages of the permitted target amount. Like the reliability results, the number of consecutive months does not vary substantially for most locations. Plots showing the same results in Tables 2.4 and 2.5 are included in Appendix A and B respectively.

This section quantifies the reliability of the various water rights in the Lower Brazos Basin. In addition, it is demonstrated that the reliability and number of consecutive months with diversion less than target is affected more by the magnitude of the drought than the target diversion rate. In other words, during dry conditions, either there is water available for diversion, or there isn't.

Table 2.3 Permitted Diversion Targets for Brazoria County Control Points identified in bwam3 WAM.

	Monthly Diversion Targets (acre-ft/month)												
Owner / Priority Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Acre-Ft/Year
THE RANDOLPH CO. ET AL 6/16/1914	22	33	65	203	398	735	865	757	250	167	101	25	3620
DONALD JOE BULANEK ET AL 6/25/1914	7	10	20	62	122	225	265	231	76	51	31	8	1107
ALBERT KUCHAR 6/25/1914	4	6	12	38	75	139	163	143	47	31	19	5	683
CLEVELAND DAVIS III ET AL 6/25/1914	3	4	8	25	50	92	109	95	31	21	13	3	454
E C STOKLEY TRUSTEE 6/29/1914	2	4	7	22	44	81	96	84	28	18	11	3	400
TOM TIGNER TRUST 6/30/1914	4	5	11	34	66	122	143	125	41	28	17	4	600
DONALD JOE BULANEK ET AL 5/9/1923	3	5	10	32	62	115	135	118	39	26	16	4	566
CHOCOLATE BAYOU WATER CO 8/3/1927	94	99	111	123	136	148	162	154	141	127	109	94	1500
DOW CHEMICAL CO 2/28/1929	1160	1540	1740	1940	2140	2480	2560	2480	1560	820	760	820	20000
C E ZWAHR ET AL 12/9/1936	3	5	9	28	56	103	121	106	35	23	14	4	506
MRS W M GARRETT 12/31/1936	9	13	27	83	163	301	354	310	102	68	42	10	1482
CHOCOLATE BAYOU WATER CO 9/21/1937	315	330	370	410	455	495	539	514	470	425	365	315	5000
A FARRER ETAL 1/16/1940	4	5	11	34	66	122	143	125	41	28	17	4	600
TEXAS DEPT OF CRIMINAL JUSTICE 4/24/1940	6	9	17	53	104	192	226	198	65	44	26	7	946
CHOCOLATE BAYOU WATER CO 10/15/1940	252	264	296	328	364	396	432	412	376	340	292	252	4000
CHOCOLATE BAYOU WATER CO 4/9/1941	126	132	148	164	182	198	216	206	188	170	146	126	2000
DOW CHEMICAL CO 2/14/1942	12828	14388	16185	18034	20061	22416	24063	23027	18750	15207	13202	11840	210000
CHOCOLATE BAYOU WATER CO 3/31/1942	126	132	148	164	182	198	216	206	188	170	146	126	2000
R L ALEXANDER & M A CROUCH 12/31/1943	6	9	17	54	106	197	231	202	67	45	27	7	968
ALVIN GOLF & COUNTRY CLUB 12/31/1945	0	0	1	3	6	11	13	11	4	2	2	0	54
BIERI FARM, INC. 3/22/1947	5	8	16	50	99	183	215	188	62	41	25	6	900
T L SMITH TRUST ET AL 1/15/1948	11	16	32	101	198	365	430	376	124	83	50	13	1800
J W ISAACS 3/31/1948	3	5	10	31	62	114	134	117	39	26	16	4	560
DOW CHEMICAL CO 4/3/1951	472	495	554	614	682	742	809	772	704	637	547	472	7500
R T MARSHALL TRUSTEE 3/31/1960	1	2	3	10	21	38	45	39	13	9	5	1	187
DOW CHEMICAL CO 4/4/1960	3771	5006	5656	6307	6957	8062	8322	8062	5072	2667	2471	2666	65020
BRAZOSPORT WATER AUTHORITY 4/4/1960	3750	3563	3412	3563	3375	3750	3788	3975	4087	4087	3975	3675	45000
JAMES SCOPEL 4/15/1962	1	1	3	9	18	32	38	33	11	7	4	1	160
BEVERLY T MCDONALD ET AL 3/30/1965	1	1	2	6	12	23	27	23	8	5	3	1	112
CHOCOLATE BAYOU WATER CO 3/14/1966	1070	1121	1257	1393	1545	1681	1834	1749	1596	1444	1240	1070	17000
JOHN R & J W ISAACS 11/15/1968	7	11	22	67	132	244	287	251	83	55	34	8	1200
A FARRER ET AL 4/9/1969	5	8	16	50	99	183	215	188	62	41	25	6	900
TIGNER IRRIGATION CO. 3/1/1971	18	27	54	168	330	609	717	627	207	138	84	21	3000
DOW CHEMICAL CO 3/8/1976	197	207	232	257	285	310	338	323	294	266	229	197	3136
C E ZWAHR ET AL 7/12/1976	12	17	20	30	43	64	72	66	29	17	13	9	392
CHOCOLATE BAYOU WATER CO 11/15/1976	1636	1714	1922	2130	2364	2571	2805	2675	2442	2208	1896	1636	26000
J V 3 INC 4/18/1983	2	3	6	20	40	73	86	75	25	17	10	3	360
DONALD JOE BULANEK ET AL 4/24/1984	7	10	21	64	125	231	272	238	79	52	32	8	1140
GARRETT RANCH INC 5/8/1984	12	18	36	112	220	406	478	418	138	92	56	14	2000
C F BROWN JR TRUSTEE 5/22/1984	4	6	12	37	72	133	157	137	45	30	18	5	657
BIERI FARM, INC. 5/29/1984	4	5	11	34	66	122	143	125	41	28	17	4	600
JOHN R & J W ISAACS 9/25/1984	5	7	14	45	88	162	191	167	55	37	22	6	800
RAYMOND LE COMPTE ET AL 10/30/1984	18	26	53	164	322	594	699	611	202	135	82	20	2925
ANNA KOLANCY 1/3/1985	1	2	4	13	25	46	54	47	16	10	6	2	225
TEXAS DEPT OF CRIMINAL JUSTICE 9/19/1985	1	1	2	6	11	20	24	21	7	5	3	1	100
REX C BAILEY JR ET AL 10/16/1985	16	23	47	146	286	528	621	543	179	120	73	18	2600

TIGNER IRRIGATION CO. 5/9/1986	2	2	5	15	29	53	63	55	18	12	7	2	262
JOHN D VIEMAN ET AL 8/29/1989	6	9	18	55	108	199	234	205	68	45	27	7	979
UNITED STATES DEPT OF ENERGY 7/14/2000	4416	3989	4416	4274	4416	4274	4416	4416	4274	4416	4274	4416	52000

Table 2.4 Reliability of Brazoria County Water Rights identified in bwam3 WAM.

	Percentage of Target Diversion										
Owner / Priority Date	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	1%
THE RANDOLPH CO. ET AL 6/16/1914	97.3	97.3	97.4	97.7	97.7	97.7	97.8	98.0	98.1	98.1	98.4
DONALD JOE BULANEK ET AL 6/25/1914	98.0	98.3	98.6	98.7	99.0	99.3	99.3	99.4	99.7	99.7	99.9
ALBERT KUCHAR 6/25/1914	99.0	99.3	99.3	99.3	99.3	99.4	99.6	99.7	99.7	99.9	99.9
CLEVELAND DAVIS III ET AL 6/25/1914	98.3	98.6	98.6	98.6	98.6	98.7	98.7	99.0	99.3	99.6	99.9
E C STOKLEY TRUSTEE 6/29/1914	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOM TIGNER TRUST 6/30/1914	98.6	98.7	99.0	99.3	99.3	99.3	99.4	99.7	99.7	99.7	99.9
DONALD JOE BULANEK ET AL 5/9/1923	96.8	97.0	97.0	97.0	97.3	97.3	97.6	97.6	97.8	97.8	98.0
CHOCOLATE BAYOU WATER CO 8/3/1927	96.7	97.0	97.4	98.0	98.4	98.6	98.6	98.7	99.0	99.4	99.9
DOW CHEMICAL CO 2/28/1929	98.8	98.8	98.8	98.8	99.0	99.0	99.3	99.4	99.7	99.7	99.9
C E ZWAHR ET AL 12/9/1936	99.3	99.3	99.3	99.3	99.4	99.6	99.7	99.7	99.7	99.9	99.9
MRS W M GARRETT 12/31/1936	97.8	98.1	98.4	98.4	98.6	98.7	98.7	98.7	99.0	99.0	99.0
CHOCOLATE BAYOU WATER CO 9/21/1937	89.9	90.9	91.5	92.1	92.8	93.5	93.8	94.7	95.7	96.0	96.7
A FARRER ETAL 1/16/1940	63.2	63.2	63.3	63.5	63.5	63.5	63.6	63.6	64.3	64.5	64.5
TEXAS DEPT OF CRIMINAL JUSTICE 4/24/1940	98.1	98.1	98.1	98.4	98.4	98.4	98.4	98.4	100.0	100.0	100.0
CHOCOLATE BAYOU WATER CO 10/15/1940	78.3	80.1	82.2	85.3	87.2	89.1	91.2	92.7	94.8	97.1	99.7
CHOCOLATE BAYOU WATER CO 4/9/1941	86.8	87.1	87.5	87.5	88.3	88.3	88.8	89.1	89.4	89.6	89.8
DOW CHEMICAL CO 2/14/1942	58.4	70.5	86.3	95.3	96.5	96.8	97.4	97.6	97.7	98.8	99.9
CHOCOLATE BAYOU WATER CO 3/31/1942	91.2	91.8	92.5	94.0	94.4	95.1	96.0	96.8	97.8	99.0	99.9
R L ALEXANDER & M A CROUCH 12/31/1943	97.7	98.1	98.4	98.7	98.8	99.4	99.6	99.6	99.6	99.9	99.9
ALVIN GOLF & COUNTRY CLUB 12/31/1945	91.2	91.2	91.2	91.2	91.2	91.2	91.2	91.2	91.2	91.2	91.2
BIERI FARM, INC. 3/22/1947	90.1	90.2	90.2	90.2	90.4	90.6	90.6	92.4	93.7	94.0	94.8
T L SMITH TRUST ET AL 1/15/1948	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
J W ISAACS 3/31/1948	70.2	72.7	74.2	77.7	80.1	81.9	83.6	84.7	86.6	86.8	86.8
DOW CHEMICAL CO 4/3/1951	56.4	59.0	61.9	63.6	65.8	68.2	70.2	73.2	78.0	85.0	95.8
R T MARSHALL TRUSTEE 3/31/1960	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6
DOW CHEMICAL CO 4/4/1960	88.5	88.8	88.9	88.9	89.1	89.1	89.2	89.6	90.2	90.2	90.5
BRAZOSPORT WATER AUTHORITY 4/4/1960	90.5	90.5	90.6	90.6	90.6	90.8	90.8	91.1	91.2	91.2	91.5
JAMES SCOPEL 4/15/1962	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.2	91.2	91.2	91.2
BEVERLY T MCDONALD ET AL 3/30/1965	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2
CHOCOLATE BAYOU WATER CO 3/14/1966	97.8	97.8	98.0	98.0	98.3	98.4	98.4	98.4	98.4	98.7	99.0
JOHN R & J W ISAACS 11/15/1968	60.1	60.3	60.3	60.3	60.4	60.4	60.6	60.7	60.7	61.2	61.3
A FARRER ET AL 4/9/1969	56.5	56.8	57.8	59.0	59.9	61.2	62.3	63.6	64.6	65.2	65.2
TIGNER IRRIGATION CO. 3/1/1971	79.6	81.7	84.3	85.5	87.1	89.4	91.8	93.7	96.0	98.0	99.7
DOW CHEMICAL CO 3/8/1976	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.6	85.8	85.9
C E ZWAHR ET AL 7/12/1976	95.8	95.8	96.0	96.0	96.0	96.0	96.0	96.1	96.1	96.3	96.3
CHOCOLATE BAYOU WATER CO 11/15/1976	47.3	49.6	51.4	52.9	54.7	55.8	61.3	65.6	71.8	80.9	89.9
J V 3 INC 4/18/1983	95.0	95.0	95.1	95.3	95.4	95.4	95.7	95.8	96.3	96.4	96.5
DONALD JOE BULANEK ET AL 4/24/1984	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GARRETT RANCH INC 5/8/1984	92.7	93.2	94.7	95.4	96.3	96.8	97.4	98.1	99.0	99.4	99.9
C F BROWN JR TRUSTEE 5/22/1984	91.9	92.2	94.5	95.3	95.4	95.7	95.7	96.0	96.1	96.3	96.5
BIERI FARM, INC. 5/29/1984	67.9	68.1	68.2	68.2	68.6	69.5	69.8	70.2	70.5	74.4	90.2
JOHN R & J W ISAACS 9/25/1984	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8
RAYMOND LE COMPTE ET AL 10/30/1984	61	62.3	64.2	66	68.9	70.5	73.1	76.4	83.2	90.9	99.3

ANNA KOLANCY 1/3/1985	100	100	100	100	100	100	100	100	100	100	100
TEXAS DEPT OF CRIMINAL JUSTICE 9/19/1985	91.9	92.4	92.4	92.7	93.1	93.2	93.2	93.2	93.2	93.5	94
REX C BAILEY JR ET AL 10/16/1985	46.5	47.6	49.4	50.8	54.2	59.7	79.4	84.6	89.5	94.2	99.1
TIGNER IRRIGATION CO. 5/9/1986	96.5	96.8	97	97	97	97.1	97.1	97.1	97.4	97.4	97.4
JOHN D VIEMAN ET AL 8/29/1989	83.6	85.3	86	88.9	90.8	91.2	91.5	91.5	91.9	91.9	92.1
UNITED STATES DEPT OF ENERGY 7/14/2000	79.1	79.3	79.3	79.4	79.9	80.3	80.6	80.7	80.9	82.4	89.8

Table 2.5 Consecutive Months at which Diversions are not possible for Brazoria County Water Rights identified in bwam3 WAM.

	Percentage of Target Diversion										
Owner / Priority Date	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	1%
THE RANDOLPH CO. ET AL 6/16/1914	4	4	4	3	3	3	3	3	3	3	3
DONALD JOE BULANEK ET AL 6/25/1914	2	2	2	2	2	1	1	1	1	1	1
ALBERT KUCHAR 6/25/1914	2	1	1	1	1	1	1	1	1	1	1
CLEVELAND DAVIS III ET AL 6/25/1914	2	2	2	2	2	2	2	2	1	1	1
E C STOKLEY TRUSTEE 6/29/1914	696	696	696	696	696	696	696	696	696	696	696
TOM TIGNER TRUST 6/30/1914	2	2	2	1	1	1	1	1	1	1	1
DONALD JOE BULANEK ET AL 5/9/1923	2	2	2	2	2	2	2	2	2	2	2
CHOCOLATE BAYOU WATER CO 8/3/1927	2	2	2	2	2	2	2	2	1	1	1
DOW CHEMICAL CO 2/28/1929	3	3	3	3	3	3	2	2	1	1	1
C E ZWAHR ET AL 12/9/1936	1	1	1	1	1	1	1	1	1	1	1
MRS W M GARRETT 12/31/1936	3	3	2	2	2	2	2	2	2	2	2
CHOCOLATE BAYOU WATER CO 9/21/1937	5	4	4	4	4	4	3	3	2	2	2
A FARRER ETAL 1/16/1940	8	8	8	8	8	8	8	8	7	7	7
TEXAS DEPT OF CRIMINAL JUSTICE 4/24/1940	2	2	2	2	2	2	2	2	0	0	0
CHOCOLATE BAYOU WATER CO 10/15/1940	9	9	5	5	5	5	4	4	4	2	1
CHOCOLATE BAYOU WATER CO 4/9/1941	5	5	5	5	5	5	5	5	5	5	5
DOW CHEMICAL CO 2/14/1942	17	17	5	5	5	5	5	5	5	3	1
CHOCOLATE BAYOU WATER CO 3/31/1942	4	4	4	4	4	4	2	2	2	1	1
R L ALEXANDER & M A CROUCH 12/31/1943	2	2	2	2	2	1	1	1	1	1	1
ALVIN GOLF & COUNTRY CLUB 12/31/1945	4	4	4	4	4	4	4	4	4	4	4
BIERI FARM, INC. 3/22/1947	4	4	4	4	4	4	4	4	4	4	4
T L SMITH TRUST ET AL 1/15/1948	0	0	0	0	0	0	0	0	0	0	0
J W ISAACS 3/31/1948	10	10	9	5	5	5	5	5	5	5	5
DOW CHEMICAL CO 4/3/1951	12	12	12	12	12	12	12	9	9	8	3
R T MARSHALL TRUSTEE 3/31/1960	5	5	5	5	5	5	5	5	5	5	5
DOW CHEMICAL CO 4/4/1960	7	7	7	7	7	7	7	7	7	7	6
BRAZOSPORT WATER AUTHORITY 4/4/1960	6	6	6	6	6	6	6	6	6	6	6
JAMES SCOPEL 4/15/1962	4	4	4	4	4	4	4	4	4	4	4
BEVERLY T MCDONALD ET AL 3/30/1965	11	11	11	11	11	11	11	11	11	11	11
CHOCOLATE BAYOU WATER CO 3/14/1966	14	14	12	12	9	9	9	9	9	5	5
JOHN R & J W ISAACS 11/15/1968	17	17	17	17	17	17	17	17	17	17	17
A FARRER ET AL 4/9/1969	8	8	8	8	8	8	8	7	7	7	7
TIGNER IRRIGATION CO. 3/1/1971	8	8	7	7	7	7	5	3	3	2	1
DOW CHEMICAL CO 3/8/1976	8	8	8	8	8	8	8	8	8	8	8
C E ZWAHR ET AL 7/12/1976	2	2	2	2	2	2	2	2	2	2	2
CHOCOLATE BAYOU WATER CO 11/15/1976	24	24	24	24	17	17	17	17	9	9	5
J V 3 INC 4/18/1983	3	3	3	3	3	3	2	2	2	2	2
DONALD JOE BULANEK ET AL 4/24/1984	0	0	0	0	0	0	0	0	0	0	0
GARRETT RANCH INC 5/8/1984	3	3	3	3	2	2	2	2	2	1	1
C F BROWN JR TRUSTEE 5/22/1984	9	9	9	9	9	9	9	9	9	9	9

BIERI FARM, INC. 5/29/1984	17	17	17	17	17	17	17	17	17	11	4
JOHN R & J W ISAACS 9/25/1984	24	24	24	24	24	24	24	24	24	24	24
RAYMOND LE COMPTE ET AL 10/30/1984	12	12	12	12	12	12	9	9	7	3	1
ANNA KOLANCY 1/3/1985	0	0	0	0	0	0	0	0	0	0	0
TEXAS DEPT OF CRIMINAL JUSTICE 9/19/1985	18	18	18	18	18	18	18	18	18	18	17
REX C BAILEY JR ET AL 10/16/1985	24	24	12	12	12	11	9	9	9	4	2
TIGNER IRRIGATION CO. 5/9/1986	11	10	10	10	10	10	10	10	10	10	10
JOHN D VIEMAN ET AL 8/29/1989	12	11	11	11	11	11	11	11	11	11	11
UNITED STATES DEPT OF ENERGY 7/14/2000	8	8	8	8	8	8	8	8	8	7	6

2.1.4 Analysis of Daily Flows

To assess water availability for BWA for time periods outside the TCEQ WAM period of record (1940-1998), INTERA modified the GCWA Daily Hydro accounting model developed to assess GCWA's water needs in the lower Brazos river basin. The modifications included:

- Addition of Harris Reservoir (10,000 acre-ft storage, 6,500 acre-ft max usage)
- Addition of Brazoria Reservoir (20,000 acre-ft storage, 15,000 acre-ft max usage)
- Addition of a "Planned" Reservoir (40,000 acre-ft storage, 30,000 acre-ft max usage)

The above reservoirs were made accessible only to Dow and BWA, and were filled using water rights owned by Dow or BWA. Either Dow or BWA would drain water from the reservoirs during times of insufficient available streamflow, with streamflow allocated to Dow, BWA, GCWA, and NRG according to the priority system. Within the model, water was first drained from Harris Reservoir, then Brazoria Reservoir and the Planned Reservoir. No consideration was made for travel times between reservoirs and water diversion points, and evaporation from the reservoirs was not included in the calculations.

INTERA simulated lower Brazos River basin water allocations using daily-averaged flow data from the USGS NWIS gauge near Hempstead, TX. Simulations were performed using data from 1939 through 2011, although separate simulations were run for each modeled year. The Daily-Hydro model assumes that Harris, Brazoria, and the Planned reservoir were full at the beginning of each modeled year. Water demands for each large water right holder (GCWA, Dow, BWA, and NRG) were based on data obtained during the development of the GCWA Daily-Hydro accounting model. Demands for Dow, however, were set to 110,000 gallons per minute as stated within a 4/26/11 presentation presented by Dow and obtained by INTERA. Demands for BWA were set as input to the Daily-Hydro model, and ranged from 1 MGD to 40 MGD, with a constant demand on every day of the calendar year.

Figure 2.2 shows the modeled diversions and shortages available to BWA at various demand levels, using 2011 flow conditions. As shown, BWA would have had a shortage of water at any given demand (1-40 MGD) under 2011 flow conditions, even with access to water stored in the Planned Reservoir. The shortages ranged from 1000 acre-ft to approximately 27,000 acre-ft depending upon BWA's daily demand and the availability of water from the Planned Reservoir. As shown in Figure 2.3, modeled shortages for BWA (in 2011) began in June and persisted through early December, with brief periods of respite due to increased rainfall/streamflow. Greater shortages were computed with larger BWA demands, and BWA was largely unable to obtain any water from its Brazos River water right during June, July, and August of 2011. Without the availability of water from the Planned Reservoir, shortages occurred earlier in the calendar year, starting in Mid April.

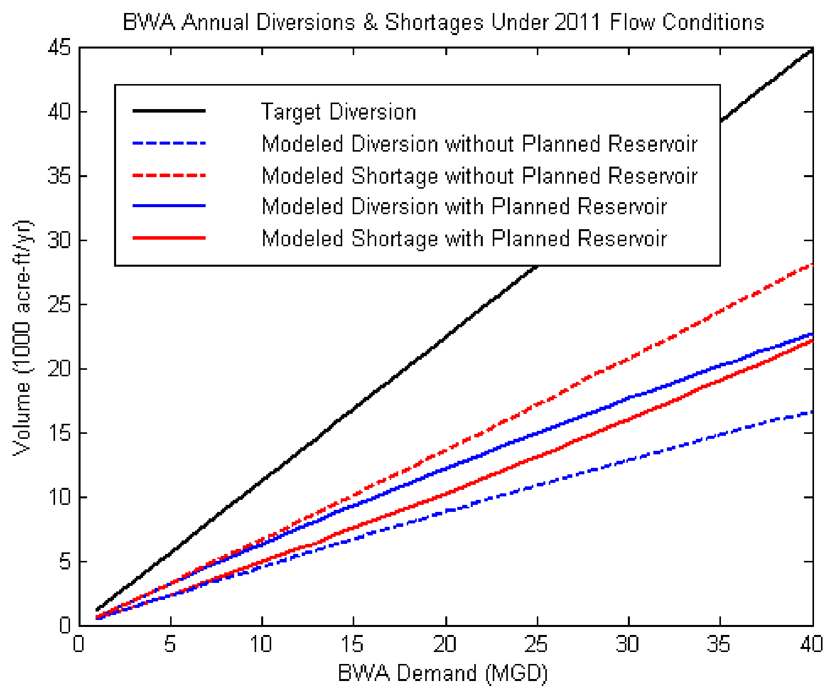


Figure 2.2 – Daily-Hydro Model Results for BWA, using 2011 Streamflow Records.

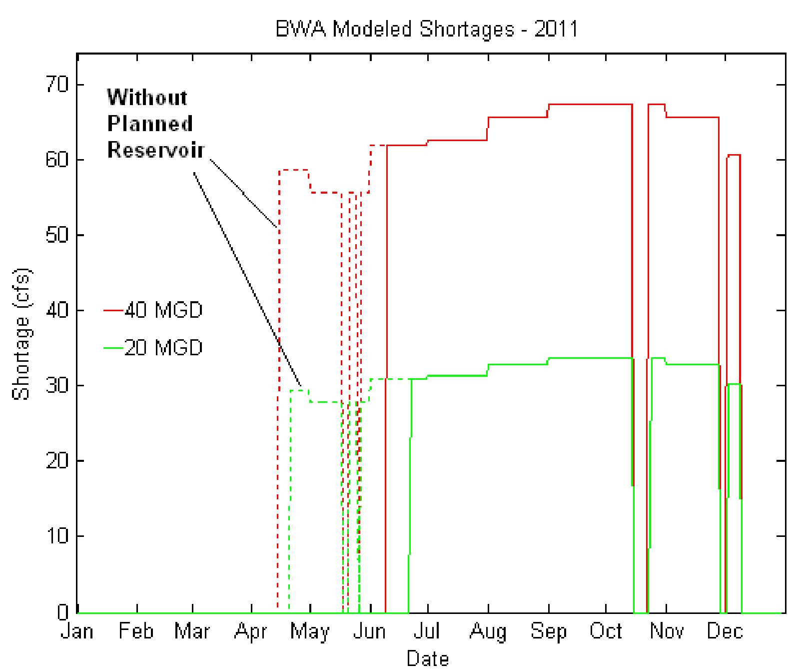


Figure 2.3 – Daily-Hydro Model Results for BWA using 2011 Stream Flow Record, showing the daily shortages over the course of the calendar year. Results shown assume 20 MGD and 40 MGD BWA demands, with and without water available from the Planned Reservoir.

Figure 2.4 presents the computed diversions and shortages for BWA from 1939 to 2011 assuming a 20 MGD demand. As shown, shortages are greatly reduced with the availability of water from the Planned Reservoir, and were eliminated completely except during the drought of record in the 1950's and during the recent years (2010-2011). The results shown in Figure 2.4 assume that Harris, Brazoria, and the Planned Reservoirs were all full at the beginning of each calendar year, therefore year-to-year trends in water availability cannot be currently assessed with the Daily Hydro model, and should not be inferred from the results shown in Figure 2.4.

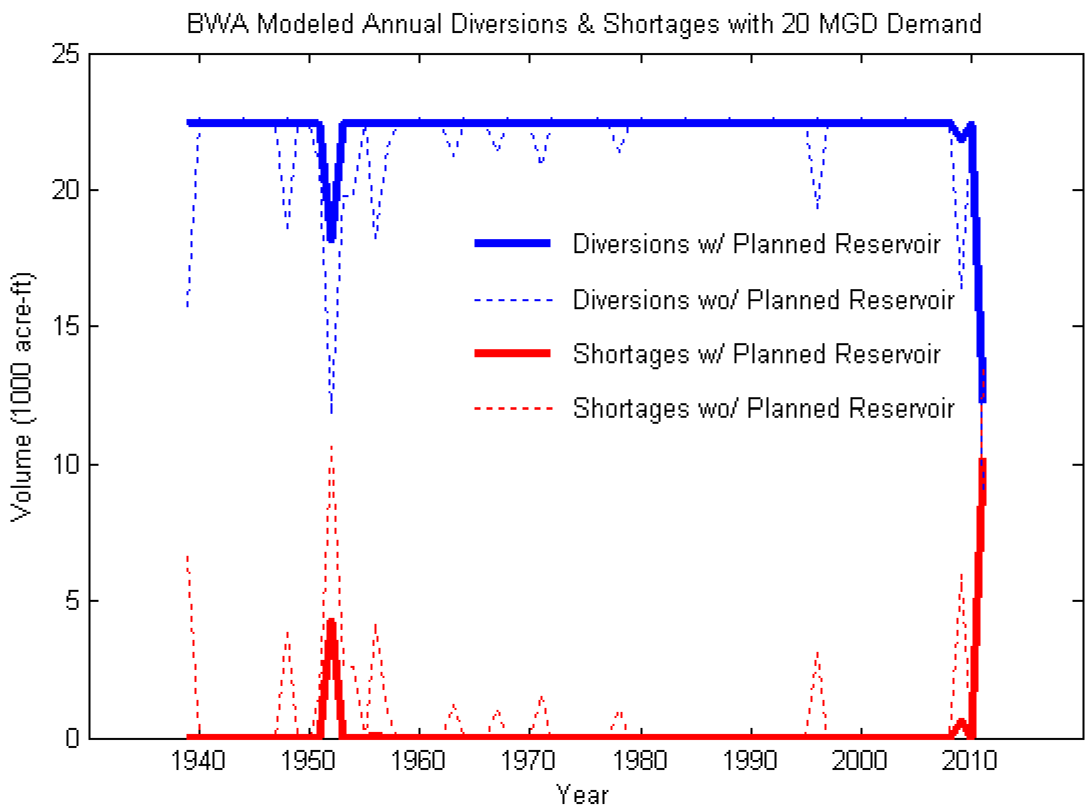


Figure 2.4 – Daily Hydro Model Results – Annual BWA Shortages & Diversions From 1939-2011 assuming a BWA demand of 20 MGD.

2.1.5 Results from the Analysis of Daily Flows

Based on the Daily-Hydro model, BWA could have diverted 16,707 acre-ft/yr in 2011, which is considered to be the single-worst year for water availability in the lower Brazos Basin. Should BWA have access to water stored in the "Planned Reservoir" under consideration by Dow, then BWA could expect to diver 22,661 acre-ft/yr under a repeat of the drought conditions experienced in 2011. These diversion amounts assumed BWA attempted to divert its full annual permitted quantity (45,000 acre-ft/yr).

2.2 Salinity as an Impediment to Surface Water Availability

The objective of this task was to quantify and tabulate the frequency, duration, and seasonality of high-salinity "events" to be expected at the Brazosport Water Authority diversion on the Brazos River. A high-salinity event was defined as a time period over which the water salinity at the Brazosport diversion exceeded either the EPA's drinking water standard for TDS (500 mg/L) or the TCEQ's drinking water standard for TDS (1,000 mg/L). Calculations were to be based on data for the time period 1940-1997 (the period of record for the Brazos Basin WAM model), and extended to 2012 if possible.

Two basic approaches to assessing the likelihood of high-salinity events at the BWA diversion are: 1) development of numerical hydrodynamic models that predict salinity under observed flow/tide conditions over the entire period of interest, and 2) comparing measured flow and salinity data collected simultaneously over a small portion of the period of interest, and then extrapolating results to the entire period of interest. Attempts at implementing approach #1 have been made by the Texas Water Development Board (TWDB) and by Texas A&M University and will be briefly discussed below. In completing this task, INTERA used the second approach with salinity data provided by the TWDB.

2.2.1 SALINITY ASSESSMENT THROUGH MODELING

Many models have been developed to predict estuarine circulation and salinity distributions. These models range in complexity from simple accounting (or 1-D "box") models to complex fully 3-Dimensional hydrodynamic models. In Texas, both accounting and hydrodynamic models have been developed for the Gulf Coast Estuaries, generally to assess water quantity/quality concerns and environmental flow requirements.

In 2001 the TWDB developed a TxBLEND hydrodynamic model of the lower Brazos River and calculated salinity distributions under varying flow regimes. They validated the model by comparing measured and observed salinity at the BWA diversion location, and achieved reasonably good results. INTERA obtained the 2001 TxBLEND model and input files from TWDB and used it to model salinity under 2009 flow and tidal conditions. Upon comparing the results with measured salinity data from the same time period, INTERA found that the TxBLEND model again achieved reasonable agreement. INTERA believes that the TxBLEND model would be suitable for predicting salinity levels at the BWA diversion location given complete flow and tidal input data. INTERA did not develop TxBLEND models for 1940-1997, however, as tidal input data was not readily available during this time period. The TWDB TxBLEND models also do not consider the salinity of water flowing into the estuary from the Brazos River watershed, and therefore may have a tendency to under-predict salinity levels at the BWA diversion point.

The TWDB is also currently in the process of refining their SELFE hydrodynamic model of the Lower Brazos River and Brazos Estuary. When complete, this model will allow for the prediction of salinity values at locations throughout the lower Brazos River based on historical measured tides and freshwater inflows. TWDB staff were uncomfortable with releasing a non-calibrated version of the lower Brazos River SELFE model for use in this project. As such, INTERA was unable to use either the input or output from the SELFE model while completing this task. The SELFE model is likely to be an improved model of the lower Brazos River, with respect to the existing TxBLEND model. The computational mechanics, algorithms, and numerical methods employed in the SELFE model (2012 Version) are more representative of the current "State of the Science" of numerical modeling than are those included within the TxBLEND model (created in 1999). INTERA believes that the results from the SELFE model will be more reliable than those from the TxBLEND model. INTERA would recommend further investigation of the SELFE model when it becomes available, especially as the model can (in theory) accurately predict dynamics of the estuarine salt wedge and predict its position within the lower Brazos River.

Water rights in Texas are routinely modeled using the WRAP software package developed by Texas A&M University. The WRAP software uses WAM models (developed by the State of Texas) to assess the reliability of water rights under a prior-appropriation system. In essence, WRAP applies a prioritized mass-balance approach to allocating water within Texas river basins. Texas A&M created the SALT model to accompany the WRAP model, and developed SALT to apply a mass-balance to saline loads to waterways. SALT therefore uses the water quantity computations from WRAP and provided salinity input loads to calculate likely salinity concentrations. The SALT model does NOT consider salinity intrusion from the Gulf of Mexico, and therefore does not assess salt-wedge movement or hydrodynamics. As a result, the SALT model may under-predict salinity levels at the BWA diversion location.

The Brazos River basin SALT model was developed in conjunction with the WRAP/SALT algorithms and is fully described in Wurbs and Lee (2009). INTERA obtained the SALT model input files directly from Dr. Ralph Wurbs upon special request, as the files are not readily available from the TCEQ or Texas A&M websites. The Brazos River SALT model was developed for the "condensed" version of the Brazos Basin WAM model ("bwam3"). The "condensed" model ("BRAC3") contains only the 14 largest reservoirs within the Brazos River basin, and the effects of the excluded reservoirs and basin water rights are included in the model by adjusting the naturalized streamflows according to the priority system. The BRAC3 model, however, does not contain a control point at the location of BWA's Brazos River diversion (at Brazoria Reservoir). The closest modeled control points within the BRAC3 model correspond to the entrance to the Gulf of Mexico and to the Rosharon gauge.

Upon running the BRAC3 SALT model, INTERA found the model predicts unrealistically high salinity values at the Gulf of Mexico under low-flow conditions. These values arise when the computed flows into the Gulf of Mexico become near-zero and the modeled salinity input load remains nearly constant. The resulting artificially high (> 100,000 Mg/L) salinity values at the Gulf of Mexico limited the utility of the SALT model for assessing salinity at the BWA diversion location. INTERA does not recommend use of the BRAC3 SALT model for this purpose. However, the SALT model could be used to generate expected salinity values for Brazos River flows at locations upstream of the Gulf of Mexico (e.g. Rosharon, Richmond), and these values could be used as input to refined versions of the SELFE or TxBLEND hydrodynamic models. The resulting hydrodynamic model could better calculate salinity distributions through the lower Brazos, assuming tidal records were available for the period of interest.

To statistically assess high-salinity events, INTERA compared flow records with salinity values measured at the Dow Pump Station intake on the Brazos River. Specifically INTERA utilized measured flow records and salinity measurements collected by and on behalf of the Texas Water Development Board during August - November 2001 and September 2008 - February 2010.

2.2.2 SALINITY ASSESSMENT THROUGH DATA EXTRAPOLATION

Standard statistical analysis techniques involve developing a relationship between two variables based on a limited set of data, and then extrapolating the relationship to apply to a large record of data for a single variable. For this project, INTERA determined a relationship between salinity and flow at the BWA diversion location based on a limited amount of measured salinity data and the flow data recorded at the times of the salinity measurements. INTERA then computed expected salinity values at the BWA diversion location based on the flow-salinity relationship and the available gauge flow records from the USGS gauges furthest downstream on the Brazos River: Richmond (#08114000 at river mile) and Rosharon (#08116650 at river mile).

The TWDB collected salinity data from the Brazos River at the BWA diversion location for the periods August 2001 to November 2001 ("Period 1") and from September 2008 to February 2010 ("Period 2"). Figures 2.5 and 2.6 show the data from Period 1 and Period 2, respectively including the measured salinity, gauge flows at Rosharon and Richmond, and measured tides at Freeport. (Figure 2.5 also shows temperature readings at the BWA diversion location). As shown in each figure, periods of measured high salinity (greater than TCEQ and EPA standards) occur during low-flow conditions, and the measured salinity values at these times show diurnal fluctuations in phase with the measured tide data. During times of higher flows, measured salinity values are lower than the TCEQ and EPA standards, and do not exhibit the diurnal fluctuations with tides.

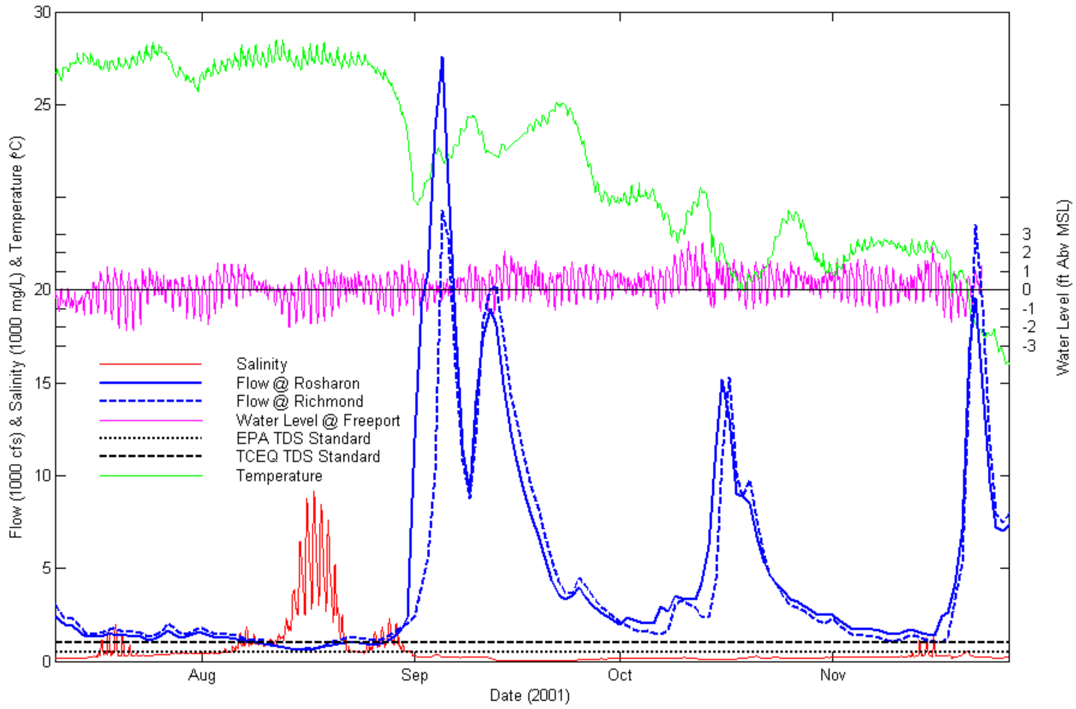


Figure 2.5 – Flow, Tide, and Salinity Data from 2001. Salinity data were collected by the TWDB at the Dow Pump Station near Brazoria Reservoir.

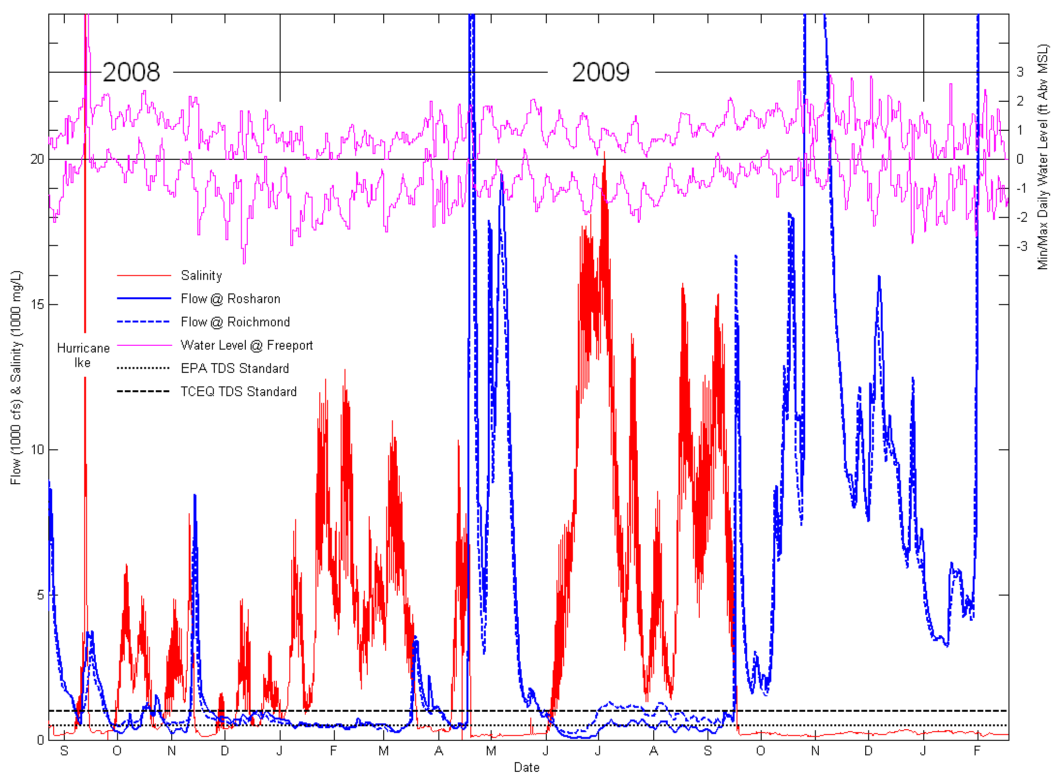


Figure 2.6 – Flow, Tide, and Salinity Data from 2008-2010. Salinity data were collected by the TWDB at the Dow Pump Station near Brazoria Reservoir.

As shown in Figure 2.6, under extreme tidal conditions (such as Hurricane Ike in September 2008), storm surges can cause high-salinity levels at the BWA diversion location, even at times when flows in the Brazos River were over 3,000 cfs. Using the flow and salinity data from 2001 and 2008-2010 as shown in Figures 2.5 and 2.6, a general relationship between river flow and salinity may be established. As shown in Figure 2.7, there exists a range of flows below which salinity levels may be expected to exceed the TCEQ and/or EPA standards for drinking water supplies. This range is roughly between 600 cfs and 2100 cfs for the EPA standard, and 600 cfs and 1750 cfs for the TCEQ standard. Specifically, based on the available measured data, when flows drop below 600 cfs (as measured at the Rosharon gauge), there is a 100% chance of observing salinity levels exceeding drinking water standards. When flow rises above 600 cfs, the likelihood of standard exceedance decreases with increasing flow. Above 1750 cfs, salinity measurements have always been below the TCEQ drinking water standard, and above 2100 cfs the EPA drinking water standard has never been observed to have been exceeded (other than during storm-surge events such as Hurricane Ike in September 2008). These relationships are shown in Figure 2.8, where the range of flows over which salinity levels may exceed standards is shown in grey. It is suspected that while the flows remain within this range, the likelihood of standard exceedance is dictated by the influence of the tides.

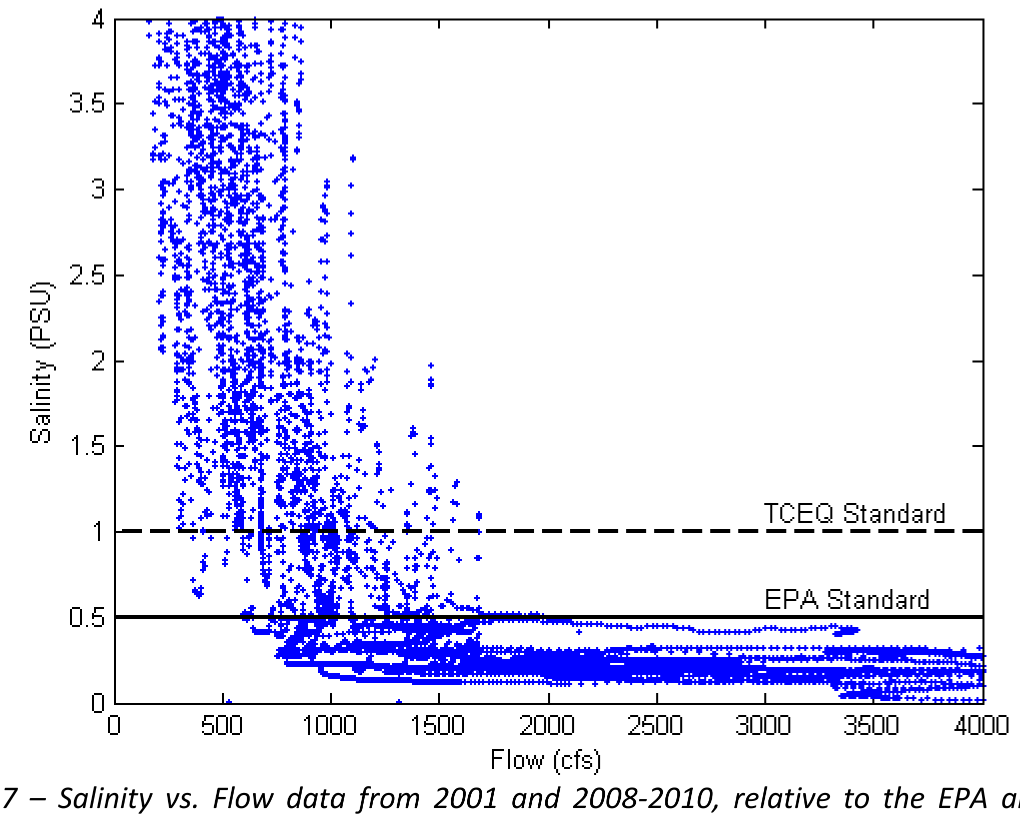


Figure 2.7 – Salinity vs. Flow data from 2001 and 2008-2010, relative to the EPA and TCEQ drinking water standards for TDS.

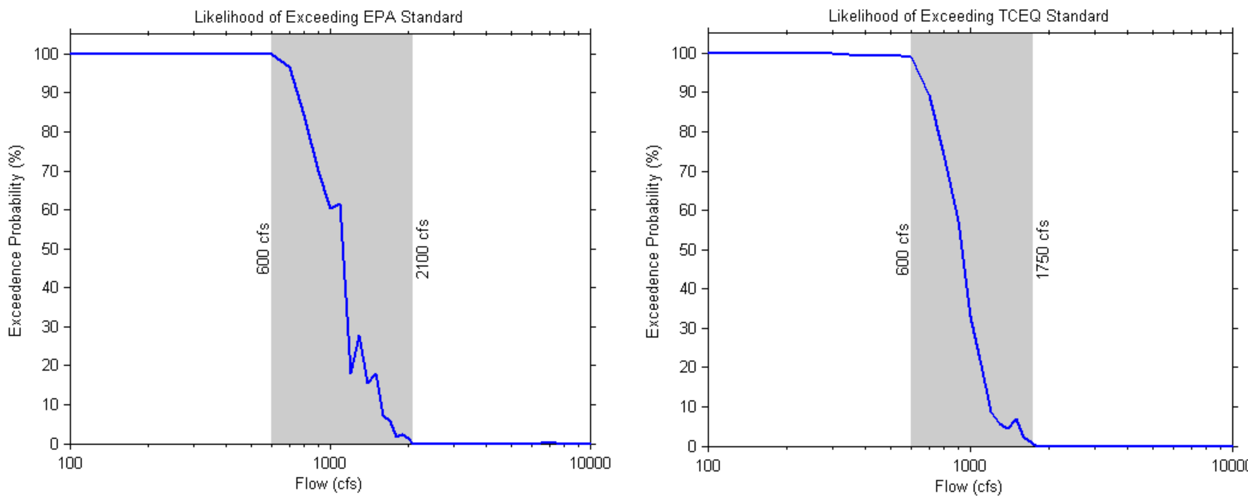


Figure 2.8 – Probability of Exceeding the EPA (left) and TCEQ (right) standards for TDS at various flow rates, based on TWDB data from 2001, 2008-2010, excluding the influence of Hurricane Ike (Sept. 2008). Grey band denotes the flow range where the exceedance probability ranges between 0% and 100%.

To statistically assess the likelihood of exceeding TDS standards at the BWA diversion location, streamflow records from the Rosharon and Richmond gauges were compared against the flow quantities shown in Figure 2.8. As shown in Figure 2.9, daily-averaged flows are available from the Richmond gauge consistently from 1924 to the present, and from the Rosharon gauge from 1967 to the present with the exception of the period from 1981 to 1984. For this analysis, records from the Richmond gauge were used whenever data from the Rosharon gauge was unavailable. Data from the Richmond gauge was also translated forward in time by 1 day to account for an average travel time for water flowing between the two gauge locations. The resulting analysis, therefore, incorporates gauge data from 1924 through November 2012.

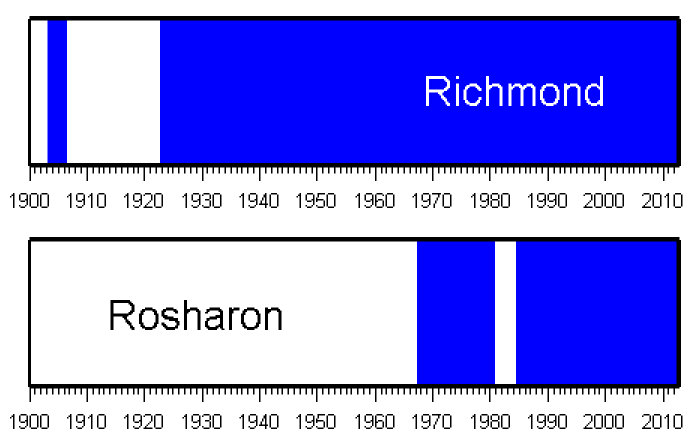


Figure 2.9 – Availability (Blue) of daily-averaged streamflow data from USGS gauges on the Brazos River at Richmond and Rosharon.

Figure 2.10 presents a flow-frequency curve for the Richmond/Rosharon flow data from 1924 to 2012, showing the likelihood of exceeding a given flow on any given day of the year. As shown on Figure 2.10, flows are 90.8% likely to be greater than 600 cfs, which is the minimum flow at which salinity levels may be less than TCEQ or EPA TDS standards. Flows are 63.0% likely to exceed 1750 cfs, thereby ensuring salinity levels lower than TDS standards set by the TCEQ. Flows are 57.9% likely to exceed 2100 cfs thereby ensuring satisfaction of the EPA TDS standard. These flow quantities are provided in Table 2.6.

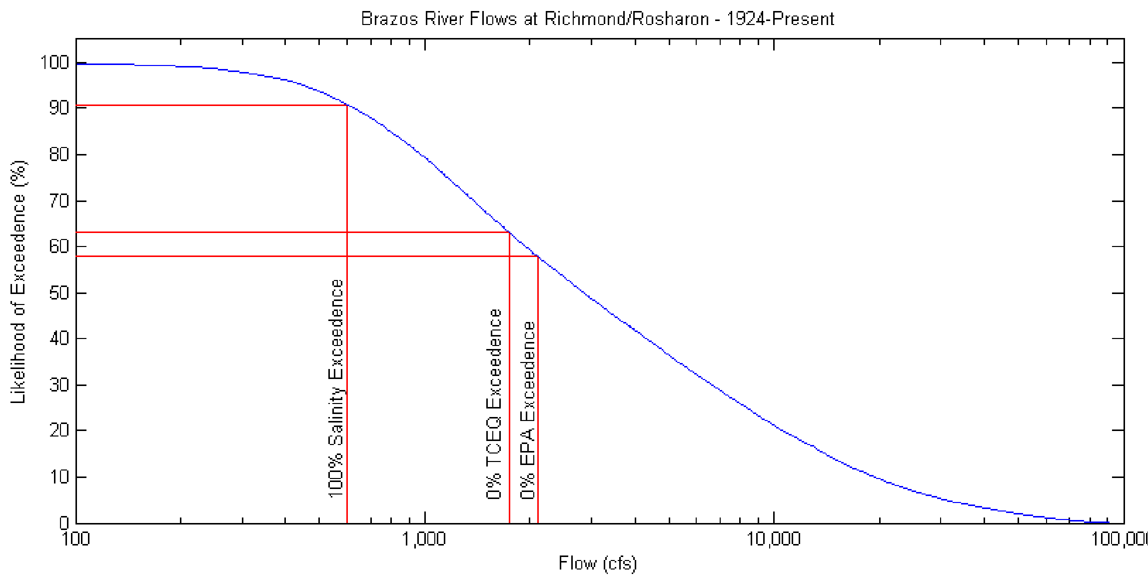


Figure 2.10 – Flow Frequency Curve for the combined Richmond/Rosharon USGS gauges, showing flow thresholds relating to salinity (Figure 2.8).

Table 2.6 – Probability of Exceeding TCEQ/EPA standards for TDS at Dow Pump Station.

Flow	TCEQ/EPA Standard Exceedance	Likelihood of Exceedance (%)
600 cfs	Yes	90.8
1,750 cfs	Possibly	63.0
2,100 cfs	No	57.9

Figures 2.11 and 2.12 shows a calendar plots detailing the time periods when the EPA and TCEQ TDS standards, respectively, are exceeded, likely to be exceeded, and satisfied at the BWA diversion location. In general, exceedance is more likely in the July-September timeframe, and appears to have been occurring more frequently in recent years. This apparent increase in the frequency of standard exceedance is not, however, significant according to the standard Mann-Kendall significance test.

The likelihood of exceedance values presented in Table 2.6 are accurate to the extent that future Brazos River flows follow similar patterns to those experienced in the 1924-2012 period of record. INTERA contends that flow patterns in more recent years (2005-2012) more accurately represent the likely future flows within the lower Brazos, as these flows incorporate the cumulative effect of all Brazos Basin water rights granted by the Texas Commission on Environmental Quality. For example, flows in 1956 (the current Brazos Basin drought of record) were higher than they would have been today due to the current existence of over 600 water rights that were granted between 1956 and 2012. Therefore should the Brazos Basin experience climatic patterns now that were identical to those in 1956, the resulting streamflow available in the lower basin are likely to be less than in 1956 because more water users currently exist in the basin. The decrease in streamflow is likely mitigated somewhat by the increase in runoff that comes with land development and population increases. Overall, however, INTERA expects lower flows to occur with greater frequency than exhibited in the historical record (Figure 2.10).

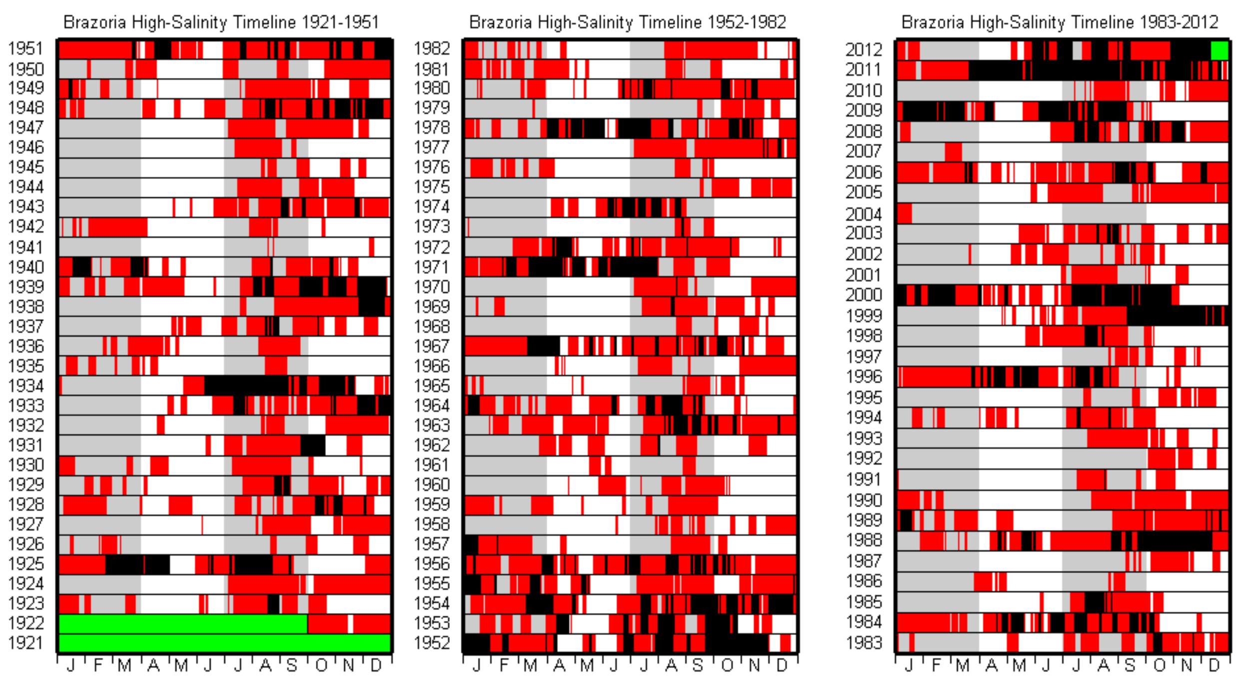


Figure 2.11 – Calendar plots showing certain exceedance (BLACK) and likely exceedance (RED) of the EPA TDS standard at the Dow Pump Station intake. Green denotes a lack of data.

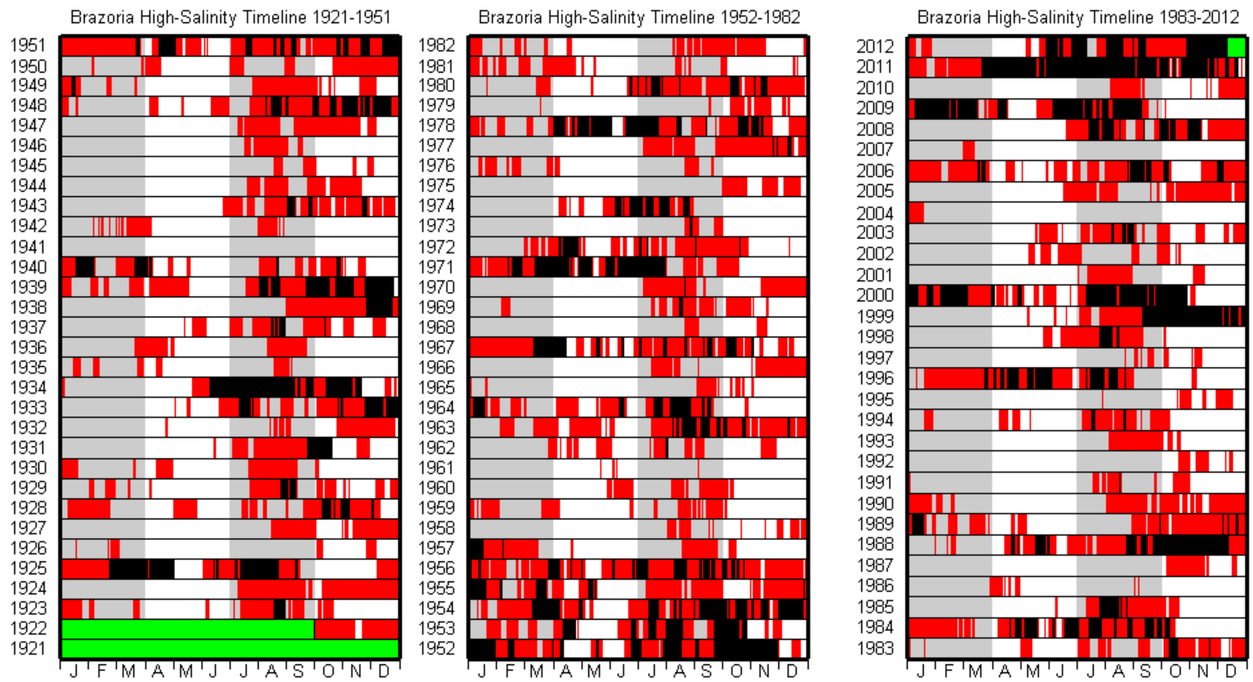


Figure 2.12 – Calendar plots showing certain exceedance (BLACK) and likely exceedance (RED) of the TCEQ TDS standard at the Dow Pump Station intake. Green denotes a lack of data.

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Young, S., Knox, P. R., Baker, E., Budge, T., Hamlin, S., Galloway, B., Kalbouss, R. and Deeds., 2010, Hydrostratigraphy of the Gulf Coast Aquifer from the Brazos River to the Rio Grande: Texas Water Development Board Report, Austin, TX.

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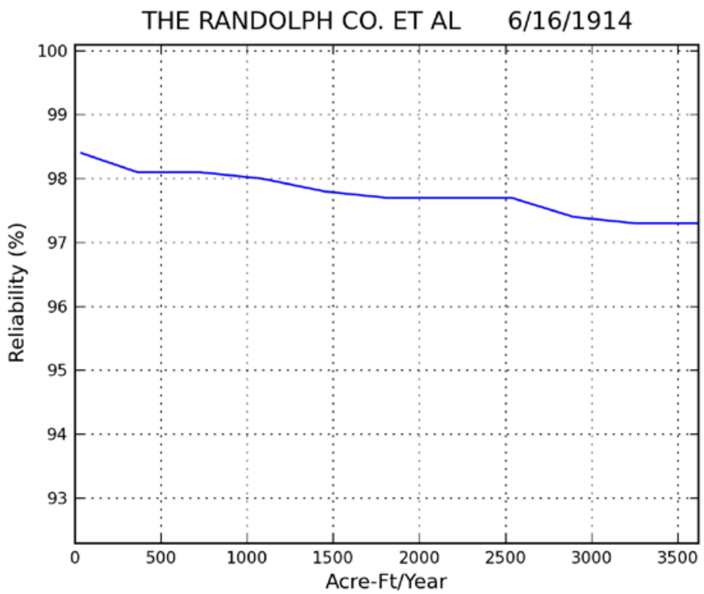
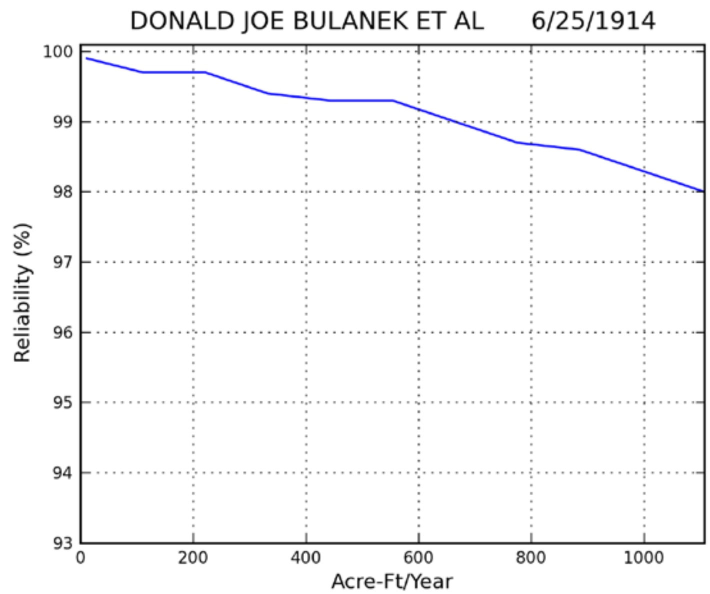
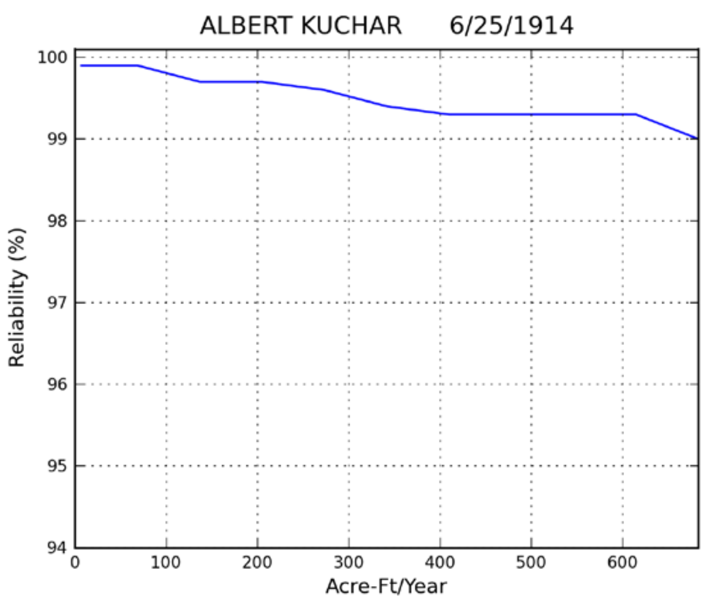
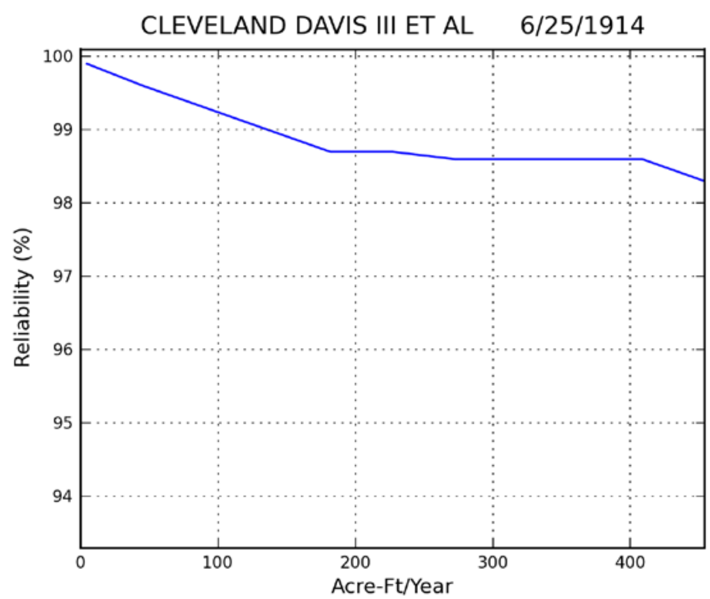
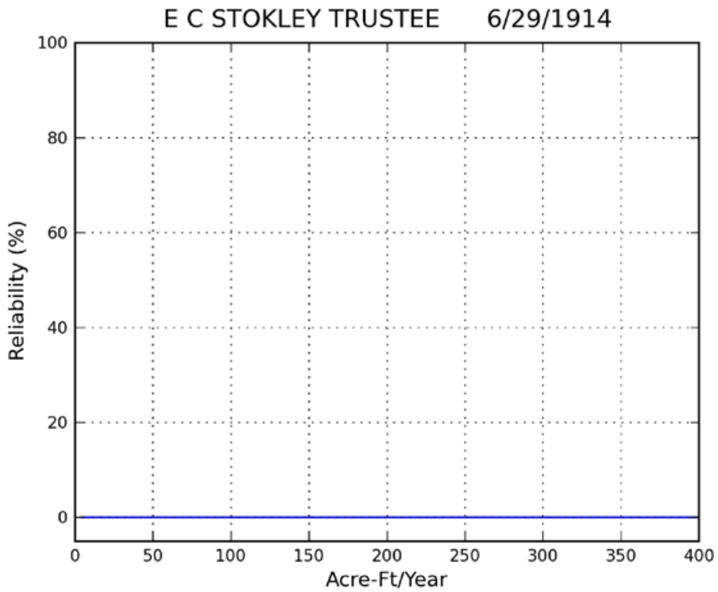
Appendix A – Monthly Reliability

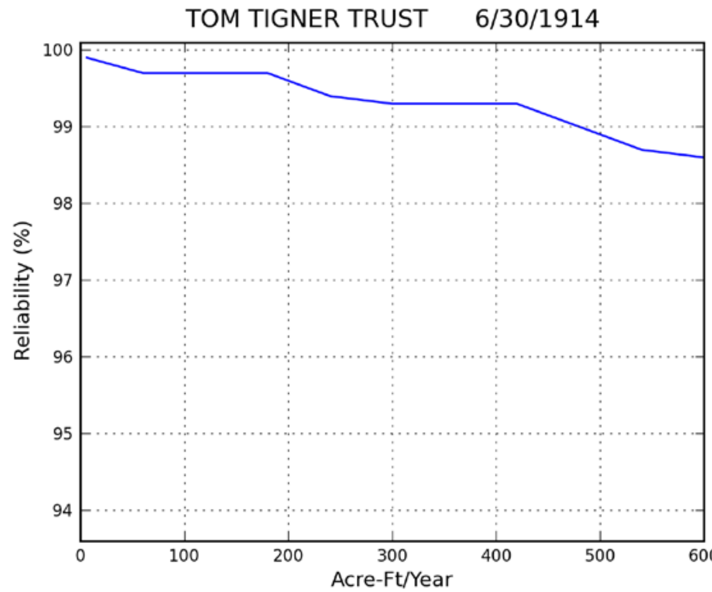

THE RANDOLPH CO. ET AL 6/16/1914
Reliability (%)
Acre-Ft/Year

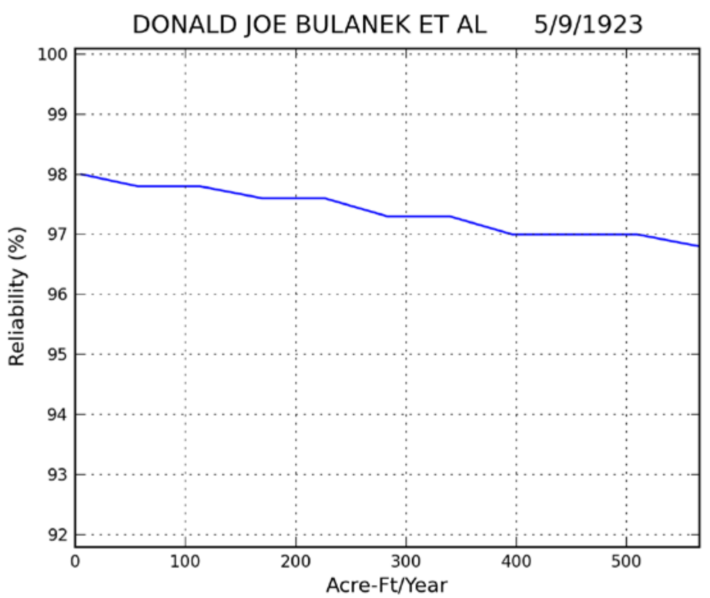

DONALD JOE BULANEK ET AL 6/25/1914
Reliability (%)
Acre-Ft/Year

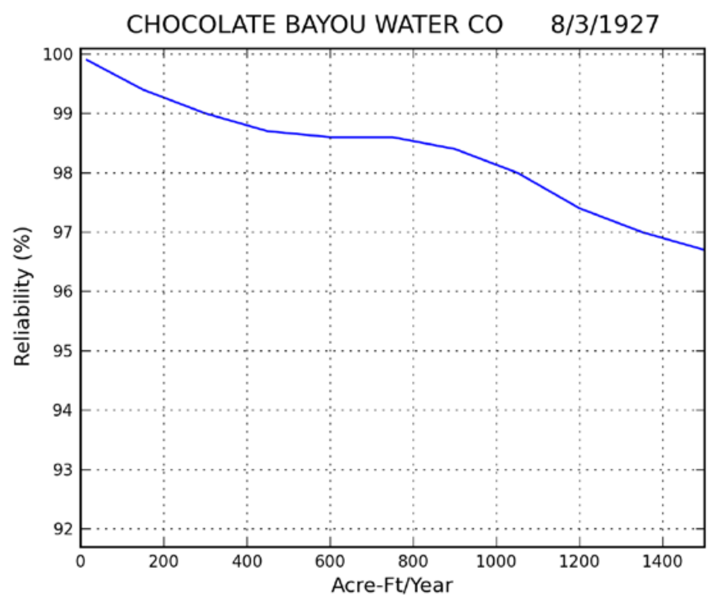

ALBERT KUCHAR 6/25/1914
Reliability (%)
Acre-Ft/Year

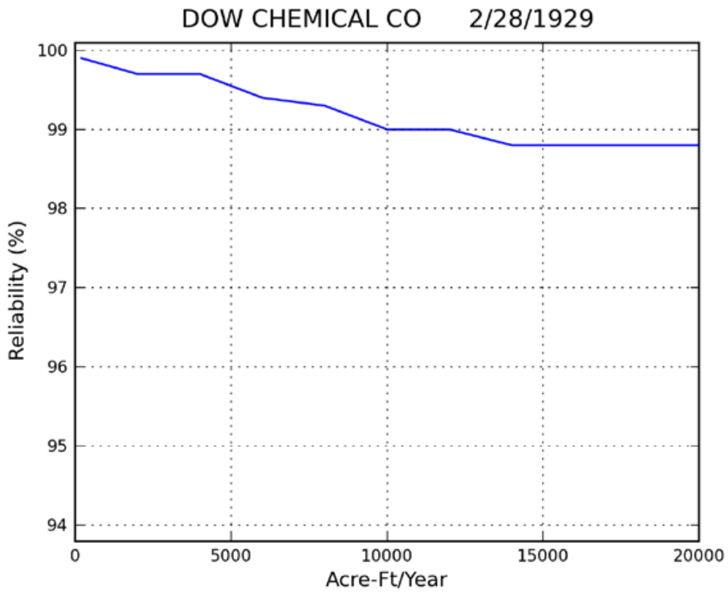

CLEVELAND DAVIS III ET AL 6/25/1914
Reliability (%)
Acre-Ft/Year


E C STOKLEY TRUSTEE 6/29/1914
Reliability (%)
Acre-Ft/Year


TOM TIGNER TRUST 6/30/1914
Reliability (%)
Acre-Ft/Year


DONALD JOE BULANEK ET AL 5/9/1923
Reliability (%)
Acre-Ft/Year


CHOCOLATE BAYOU WATER CO 8/3/1927
Reliability (%)
Acre-Ft/Year


DOW CHEMICAL CO 2/28/1929
Reliability (%)
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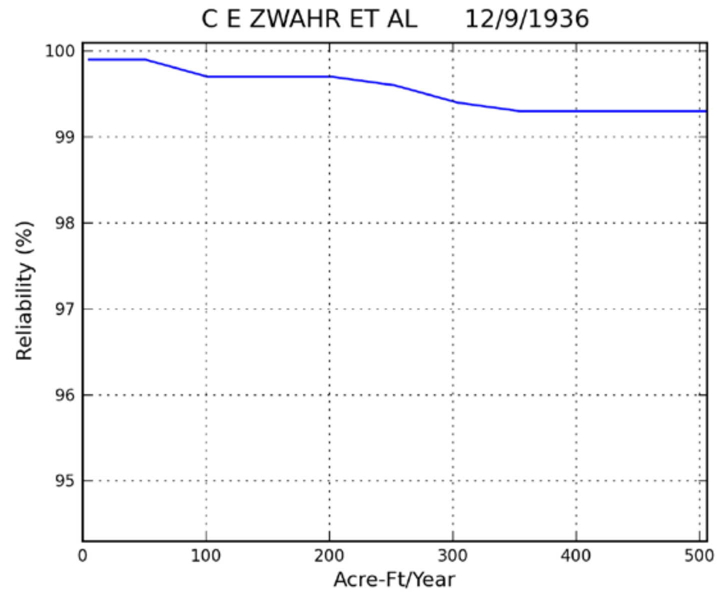
98
97
96
95
94
0
5000
10000
15000
20000
Acre-Ft/Year


C E ZWAHR ET AL 12/9/1936
Reliability (%)
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96
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400
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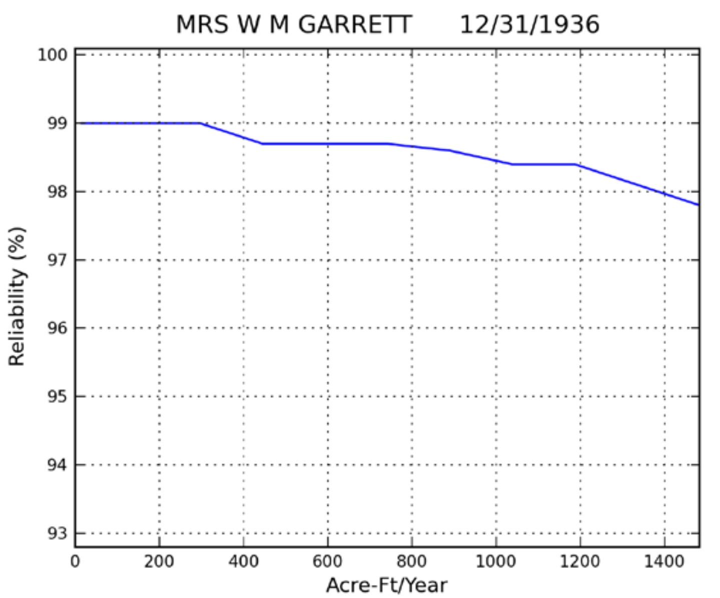
Acre-Ft/Year


MRS W M GARRETT 12/31/1936
Reliability (%)
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95
94
93
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200
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600
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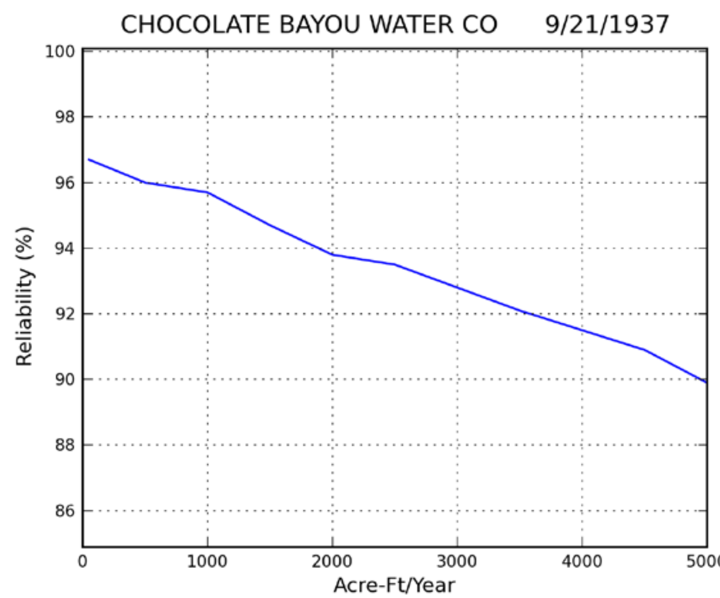
1200
1400
Acre-Ft/Year


CHOCOLATE BAYOU WATER CO 9/21/1937
Reliability (%)
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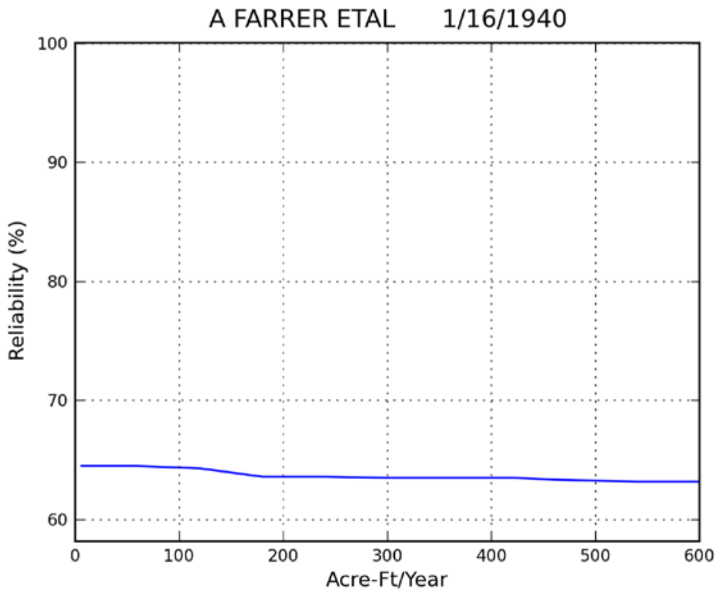
96
94
92
90
88
86
0
1000
2000
3000
4000
5000
Acre-Ft/Year


A FARRER ETAL 1/16/1940
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60
Reliability (%)
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100
200
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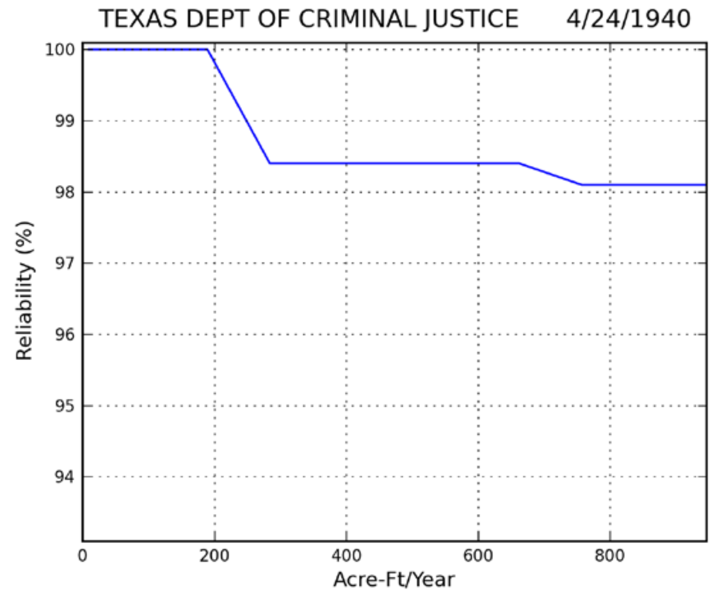
600
Acre-Ft/Year


TEXAS DEPT OF CRIMINAL JUSTICE 4/24/1940
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99
98
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95
94
Reliability (%)
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200
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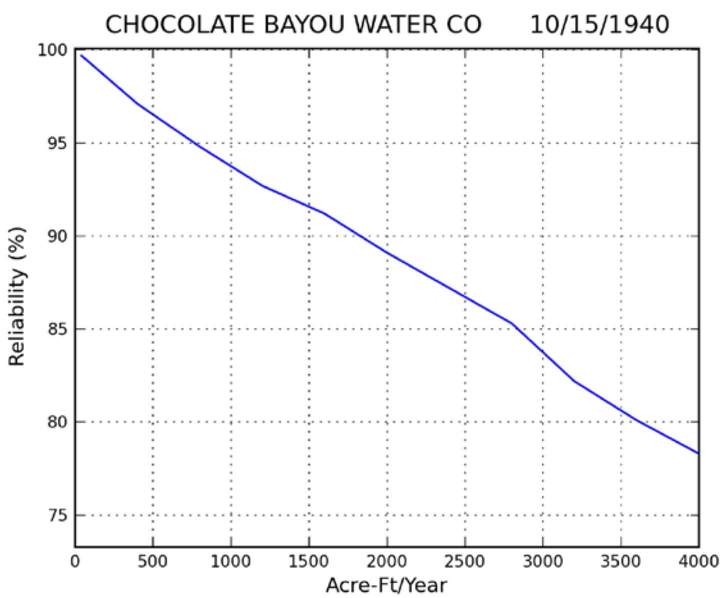
800
Acre-Ft/Year


CHOCOLATE BAYOU WATER CO 10/15/1940
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95
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75
Reliability (%)
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500
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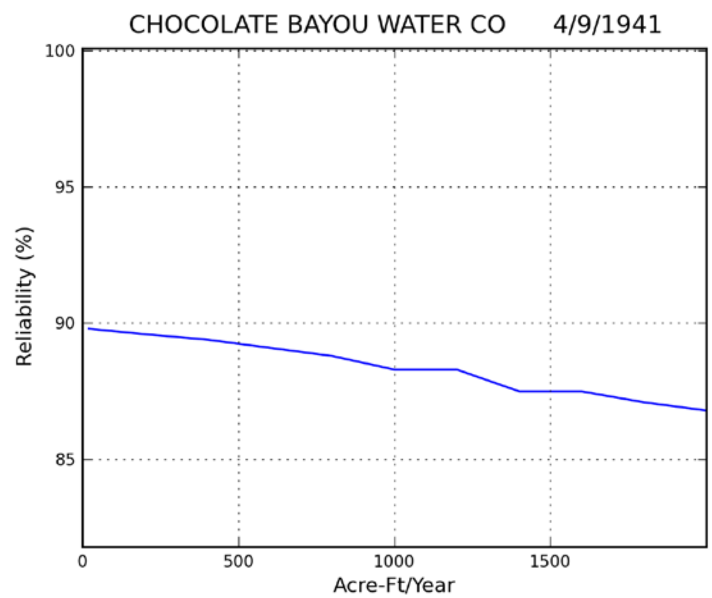
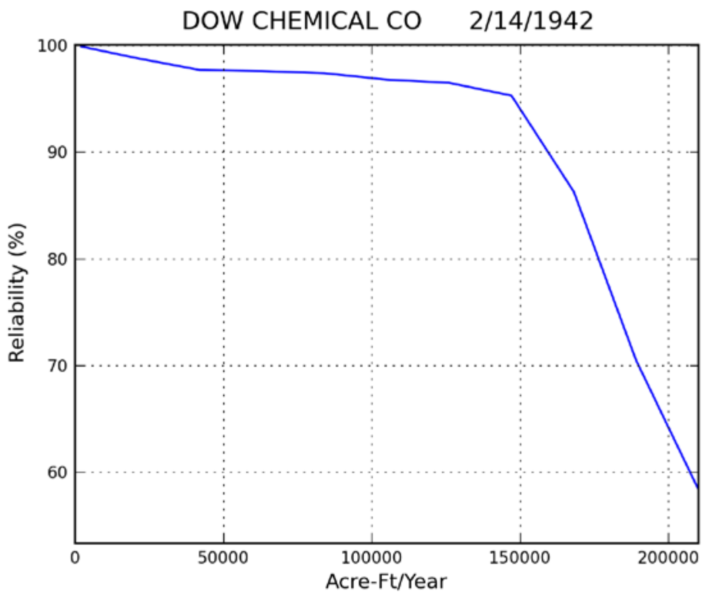
3000
3500
4000
Acre-Ft/Year


CHOCOLATE BAYOU WATER CO 4/9/1941
100
95
90
85
Reliability (%)
0
500
1000
1500
Acre-Ft/Year


DOW CHEMICAL CO 2/14/1942
Reliability (%)
Acre-Ft/Year
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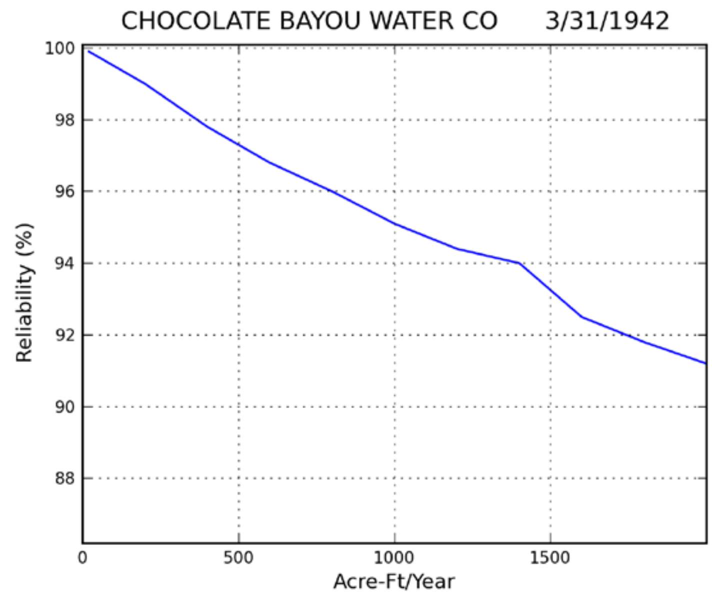
CHOCOLATE BAYOU WATER CO 3/31/1942
Reliability (%)
Acre-Ft/Year
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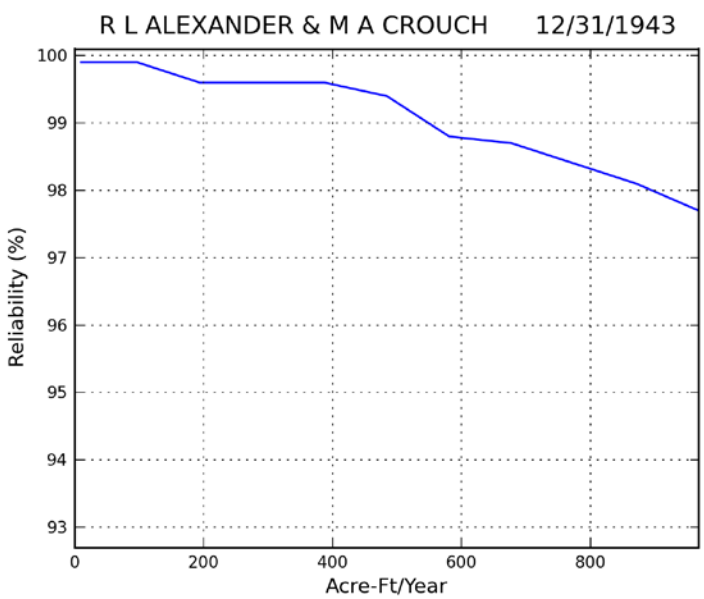
R L ALEXANDER & M A CROUCH 12/31/1943
Reliability (%)
Acre-Ft/Year
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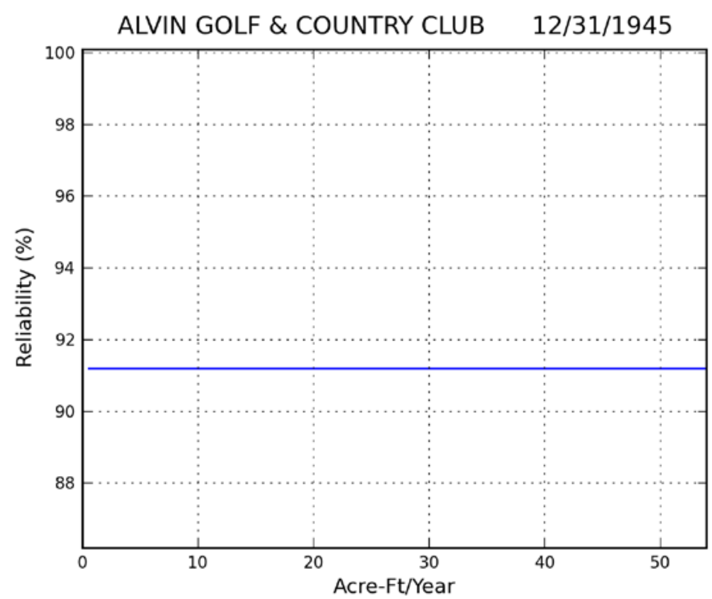
ALVIN GOLF & COUNTRY CLUB 12/31/1945
Reliability (%)
Acre-Ft/Year
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40
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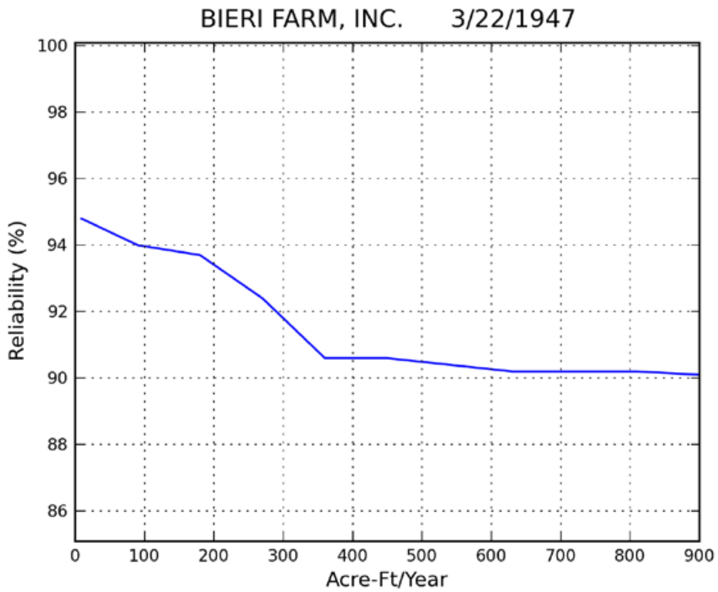
BIERI FARM, INC. 3/22/1947
Reliability (%)
Acre-Ft/Year
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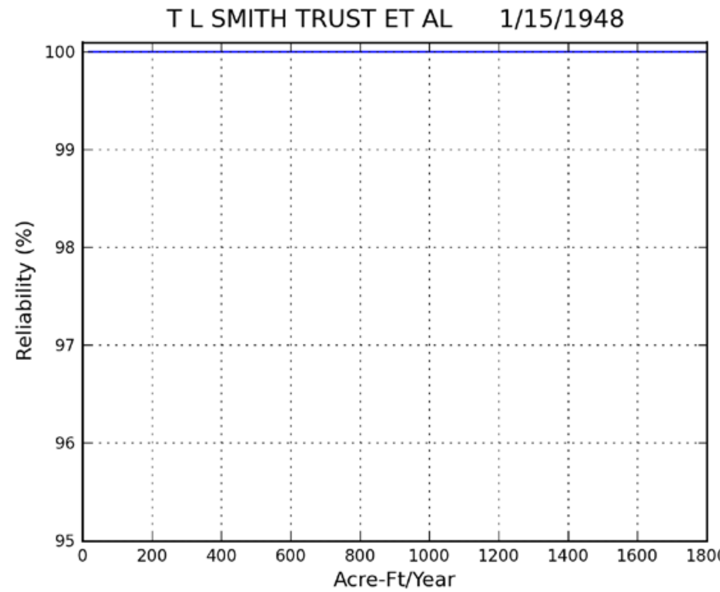
T L SMITH TRUST ET AL 1/15/1948
Reliability (%)
Acre-Ft/Year
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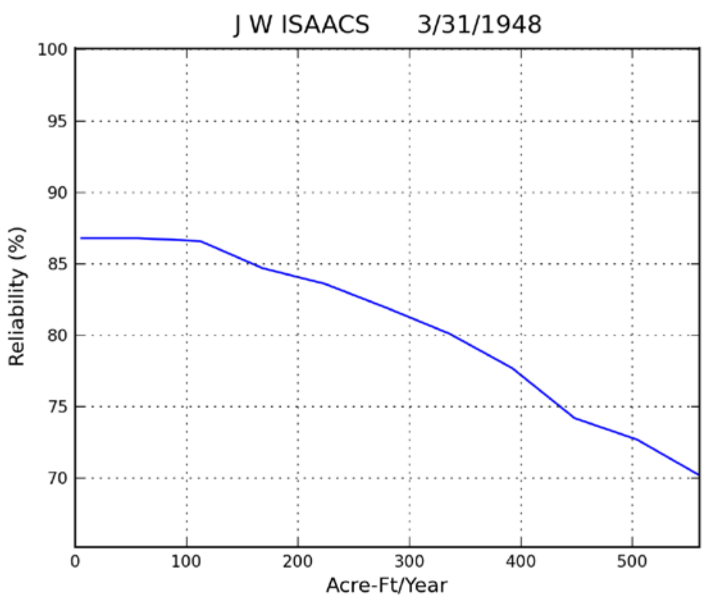
J W ISAACS 3/31/1948
Reliability (%)
Acre-Ft/Year
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85
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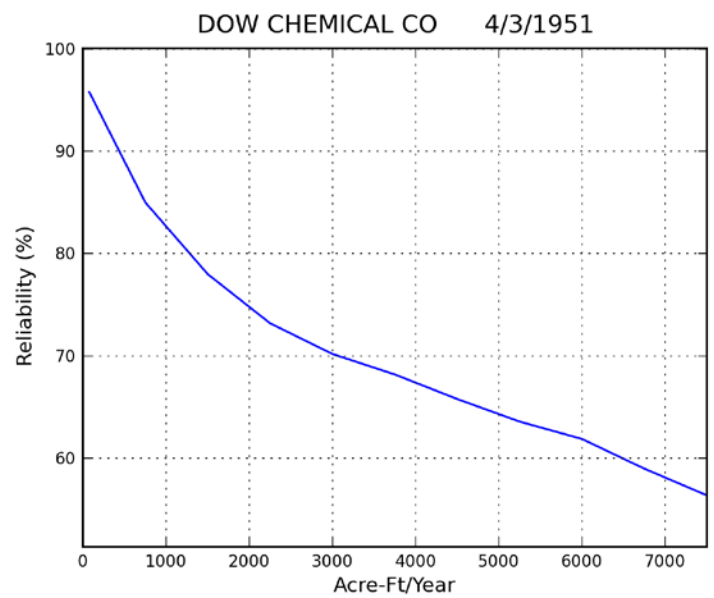
DOW CHEMICAL CO 4/3/1951
Reliability (%)
Acre-Ft/Year
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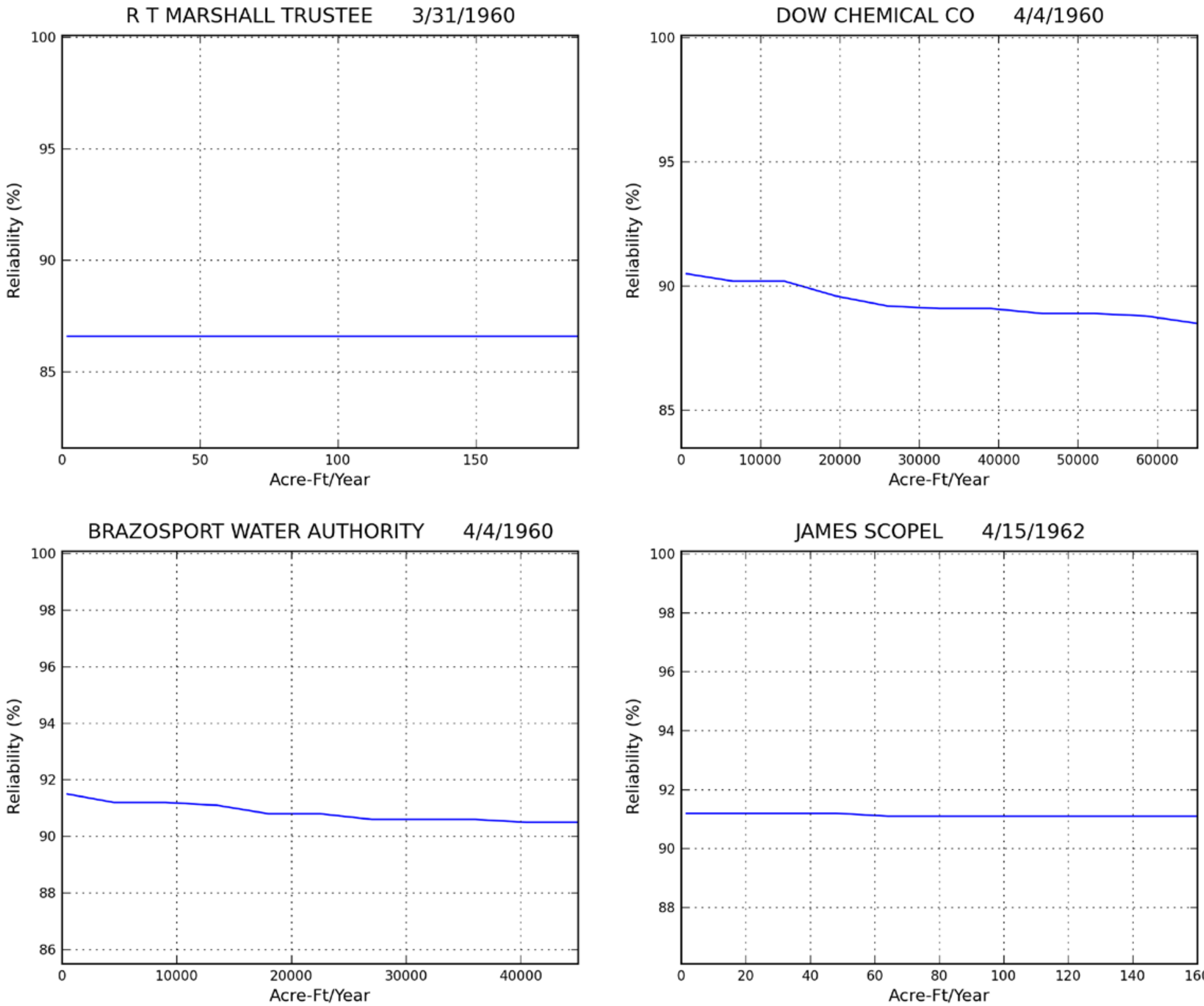
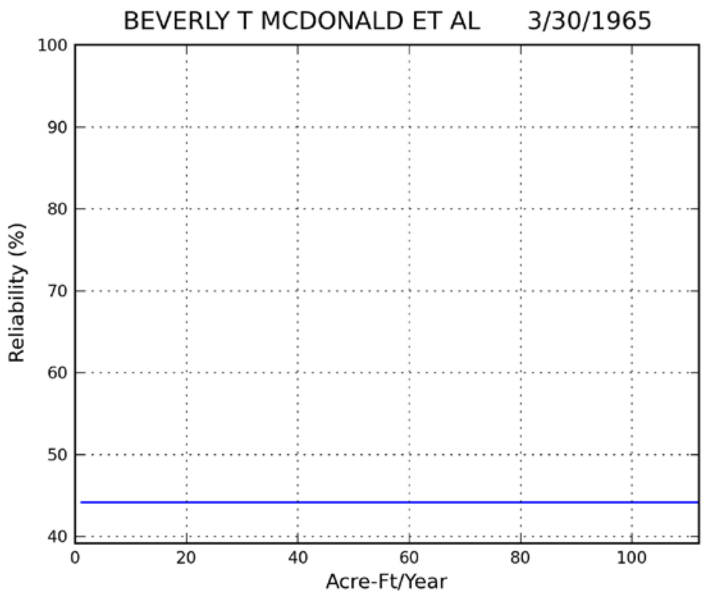
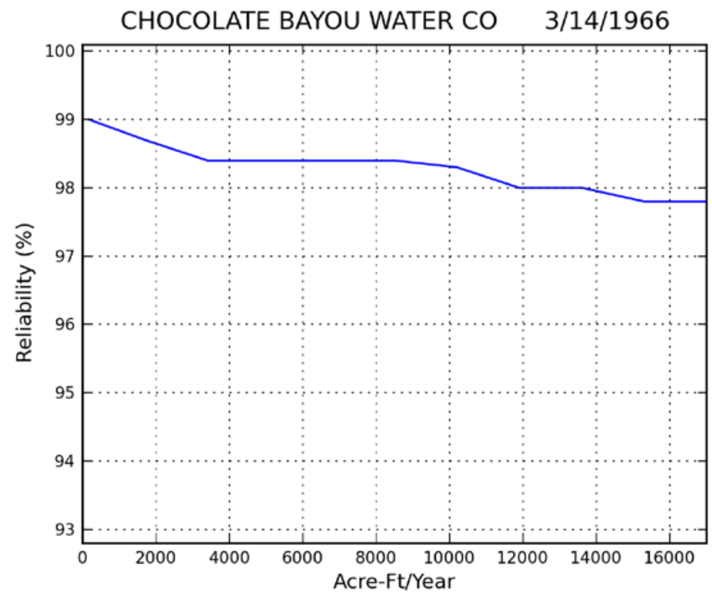
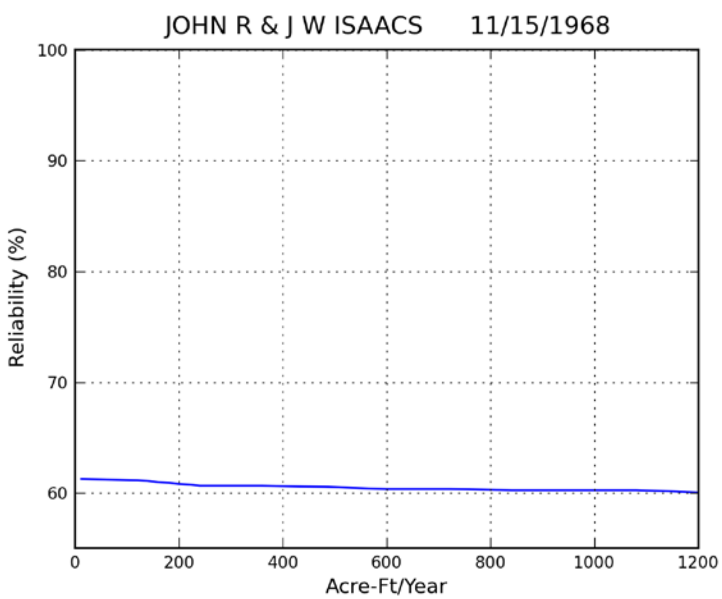
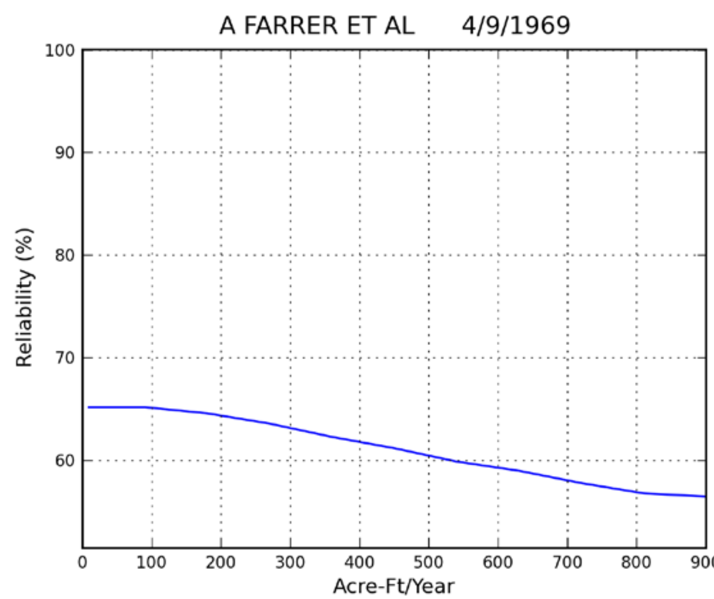
4000
5000
6000
7000

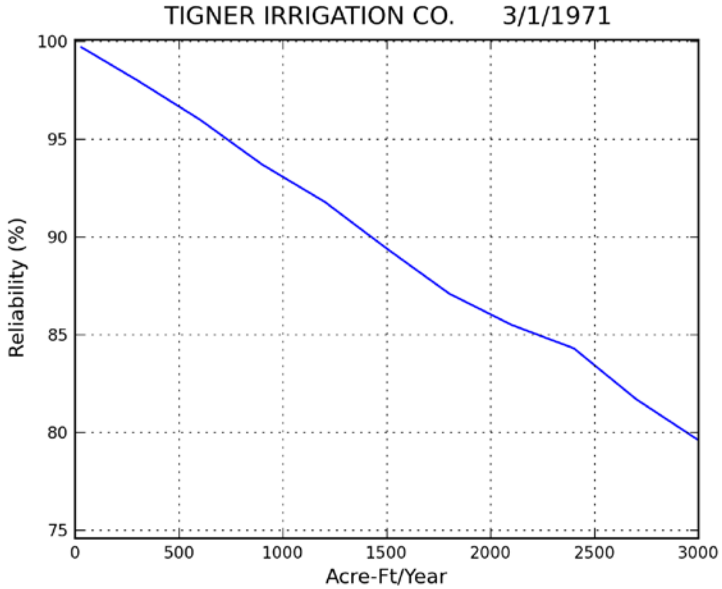

R T MARSHALL TRUSTEE 3/31/1960
Reliability (%)
Acre-Ft/Year
DOW CHEMICAL CO 4/4/1960
Reliability (%)
Acre-Ft/Year
BRAZOSPORT WATER AUTHORITY 4/4/1960
Reliability (%)
Acre-Ft/Year
JAMES SCOPEL 4/15/1962
Reliability (%)
Acre-Ft/Year

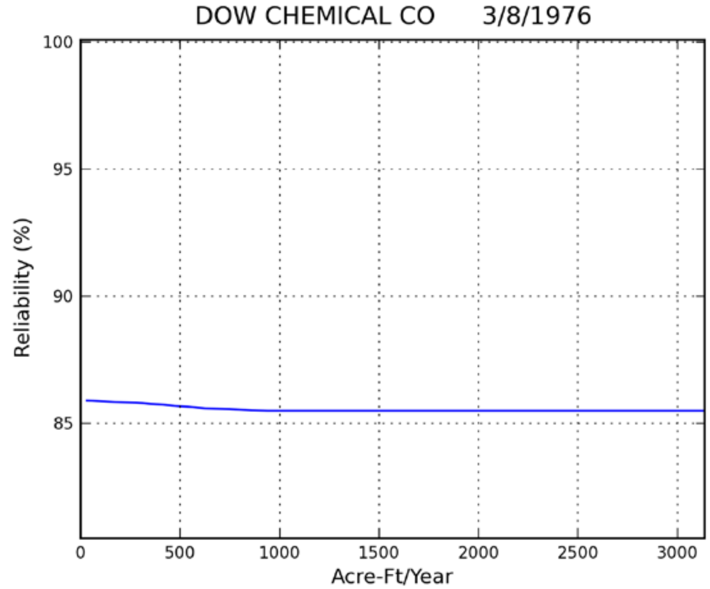

BEVERLY T MCDONALD ET AL 3/30/1965
Reliability (%)
Acre-Ft/Year

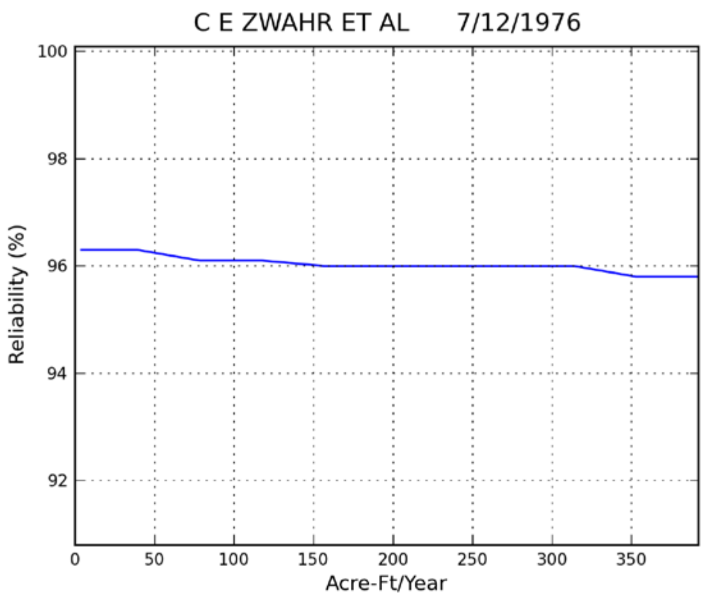

CHOCOLATE BAYOU WATER CO 3/14/1966
Reliability (%)
Acre-Ft/Year

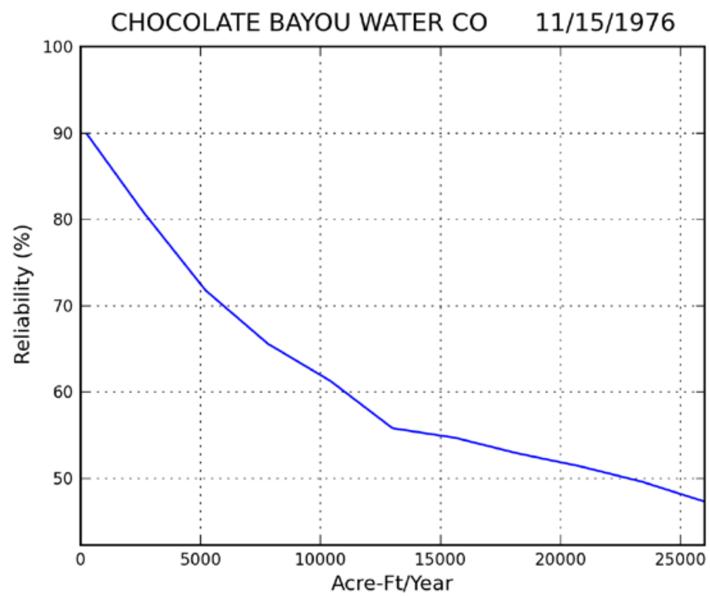

JOHN R & J W ISAACS 11/15/1968
Reliability (%)
Acre-Ft/Year

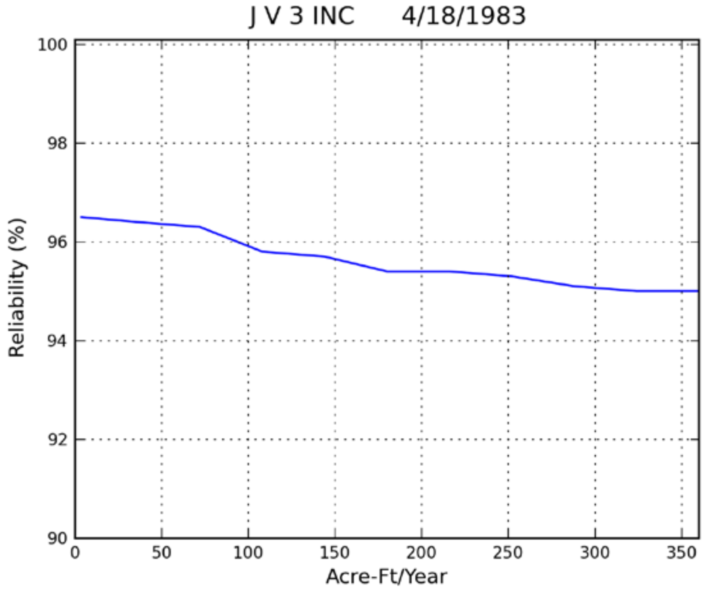

A FARRER ET AL 4/9/1969
Reliability (%)
Acre-Ft/Year

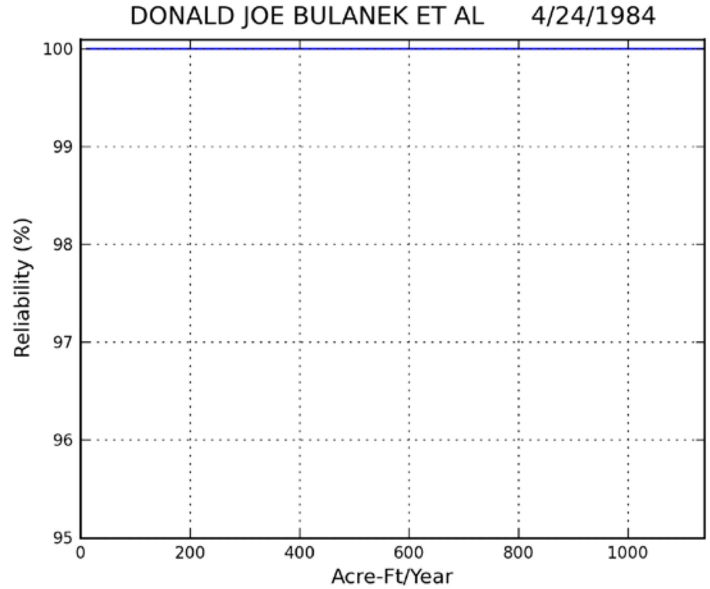

TIGNER IRRIGATION CO. 3/1/1971
Reliability (%)
Acre-Ft/Year
100
95
90
85
80
75
0
500
1000
1500
2000
2500
3000

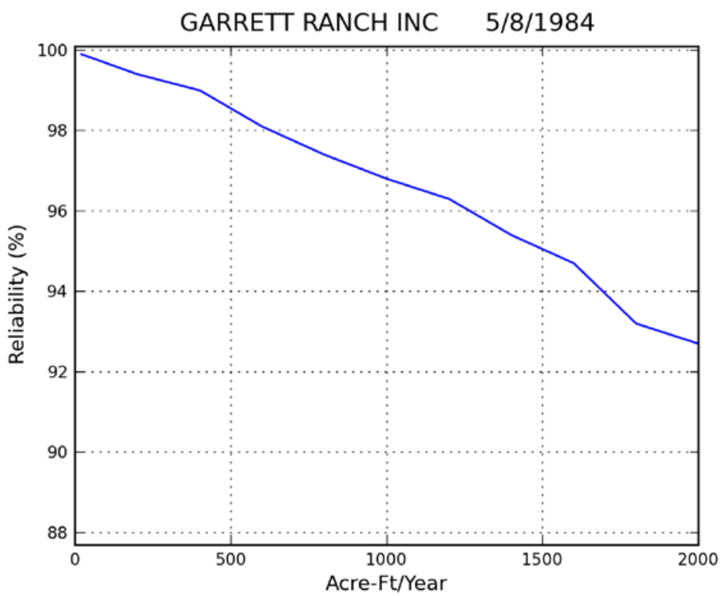

DOW CHEMICAL CO 3/8/1976
Reliability (%)
Acre-Ft/Year
100
95
90
85
0
500
1000
1500
2000
2500
3000

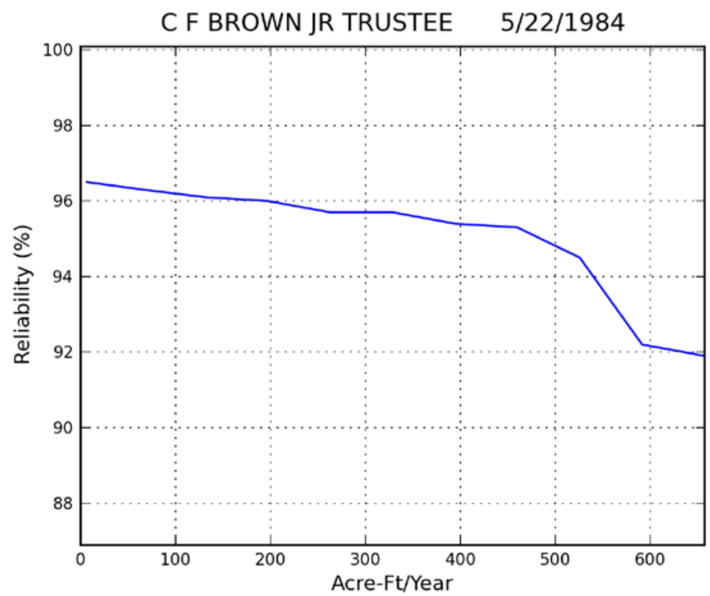

C E ZWAHR ET AL 7/12/1976
Reliability (%)
Acre-Ft/Year
100
98
96
94
92
0
50
100
150
200
250
300
350

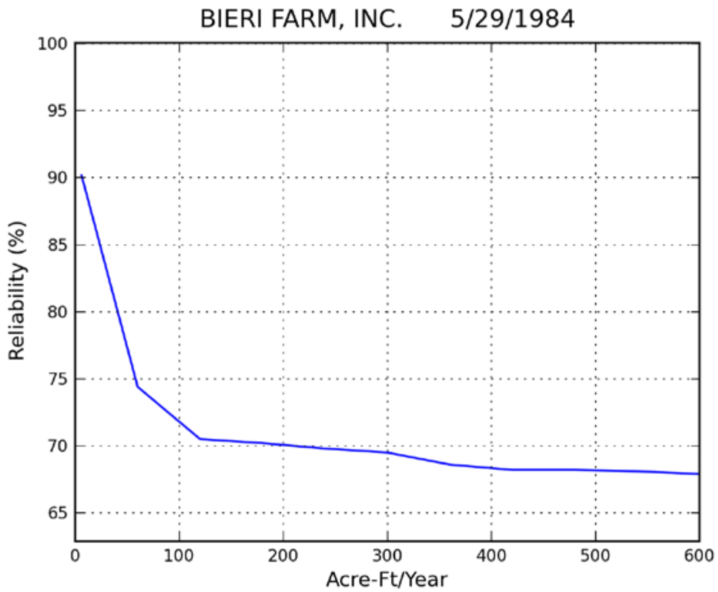

CHOCOLATE BAYOU WATER CO 11/15/1976
Reliability (%)
Acre-Ft/Year
100
90
80
70
60
50
0
5000
10000
15000
20000
25000

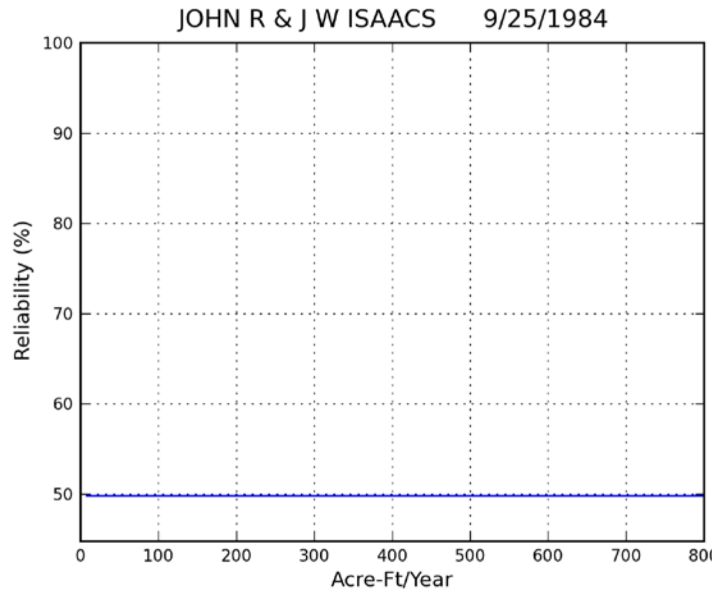

J V 3 INC 4/18/1983
Reliability (%)
Acre-Ft/Year
100
98
96
94
92
90
0
50
100
150
200
250
300
350

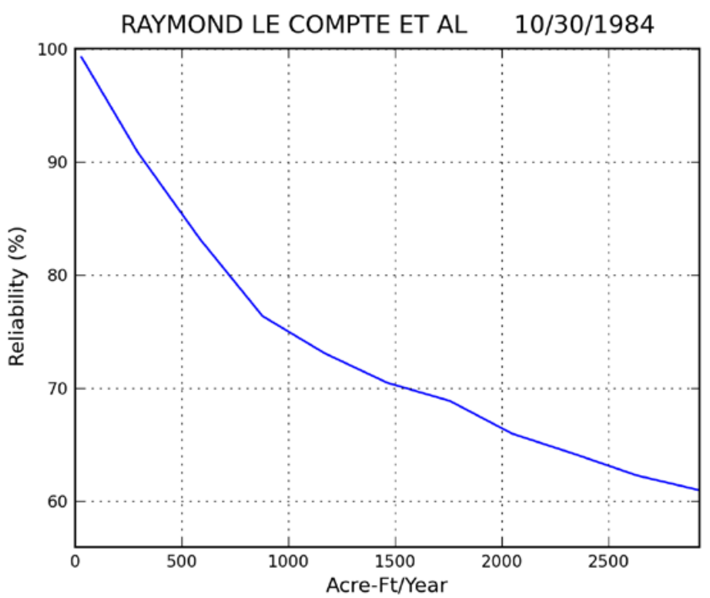

DONALD JOE BULANEK ET AL 4/24/1984
Reliability (%)
Acre-Ft/Year
100
99
98
97
96
95
0
200
400
600
800
1000

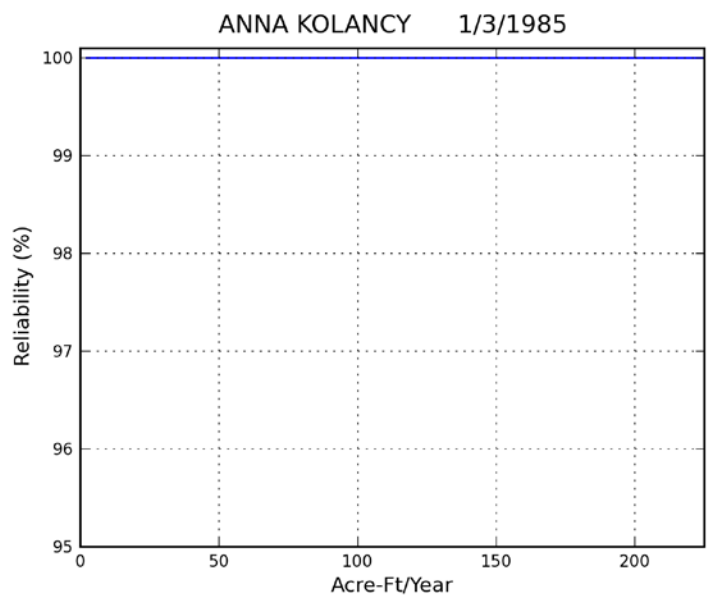

GARRETT RANCH INC 5/8/1984
Reliability (%)
Acre-Ft/Year
100
98
96
94
92
90
88
0
500
1000
1500
2000

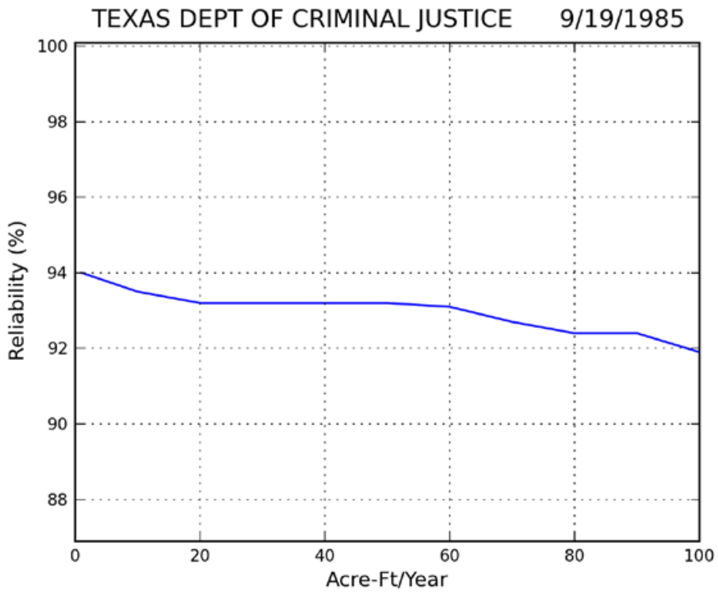

C F BROWN JR TRUSTEE 5/22/1984
Reliability (%)
Acre-Ft/Year
100
98
96
94
92
90
88
0
100
200
300
400
500
600

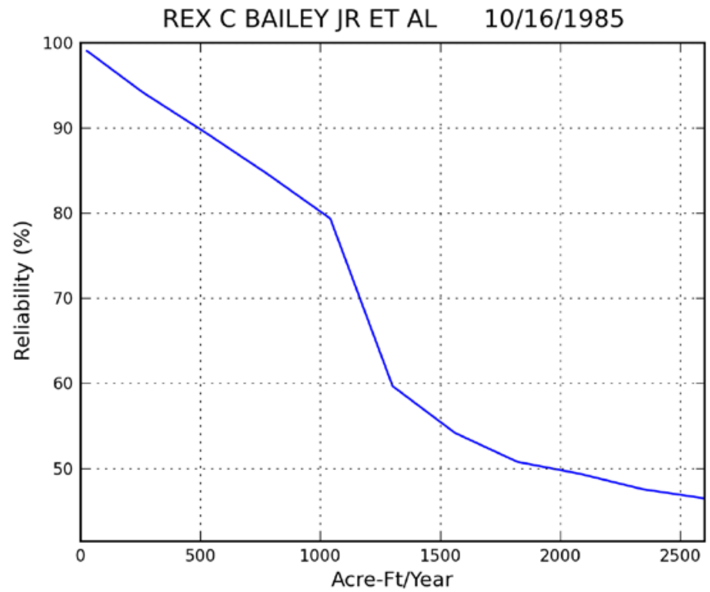

BIERI FARM, INC. 5/29/1984
Reliability (%)
100
95
90
85
80
75
70
65
0
100
200
300
400
500
600
Acre-Ft/Year

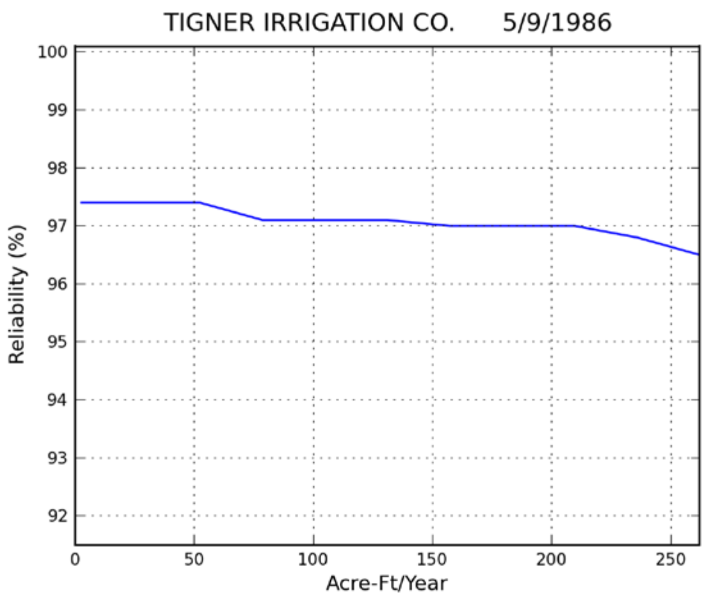

JOHN R & J W ISAACS 9/25/1984
Reliability (%)
100
90
80
70
60
50
0
100
200
300
400
500
600
700
800
Acre-Ft/Year

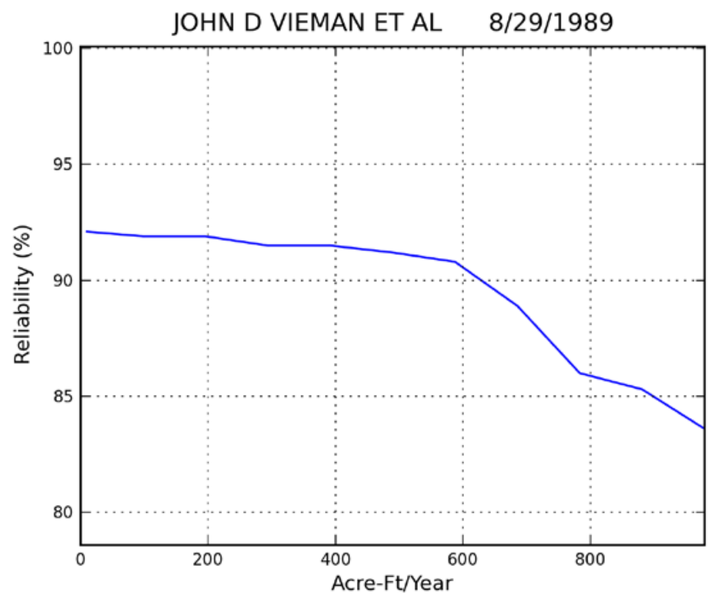

RAYMOND LE COMPTE ET AL 10/30/1984
Reliability (%)
100
90
80
70
60
0
500
1000
1500
2000
2500
Acre-Ft/Year

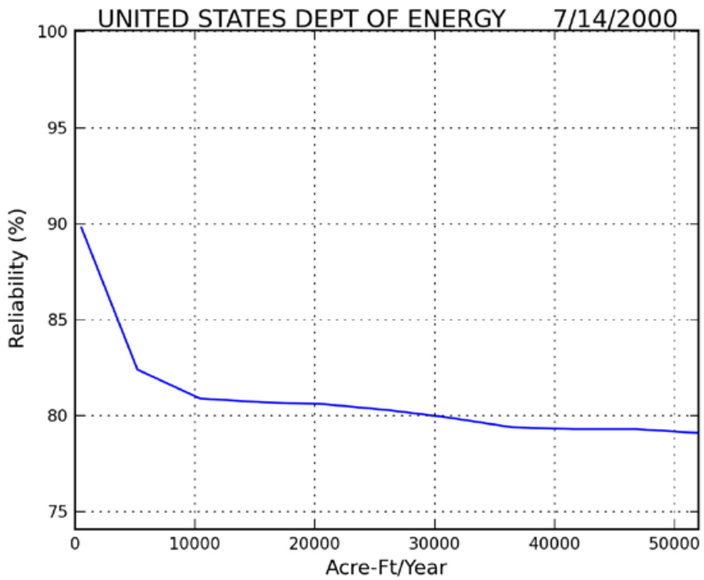

ANNA KOLANCY 1/3/1985
Reliability (%)
100
99
98
97
96
95
0
50
100
150
200
Acre-Ft/Year


TEXAS DEPT OF CRIMINAL JUSTICE 9/19/1985
Reliability (%)
Acre-Ft/Year

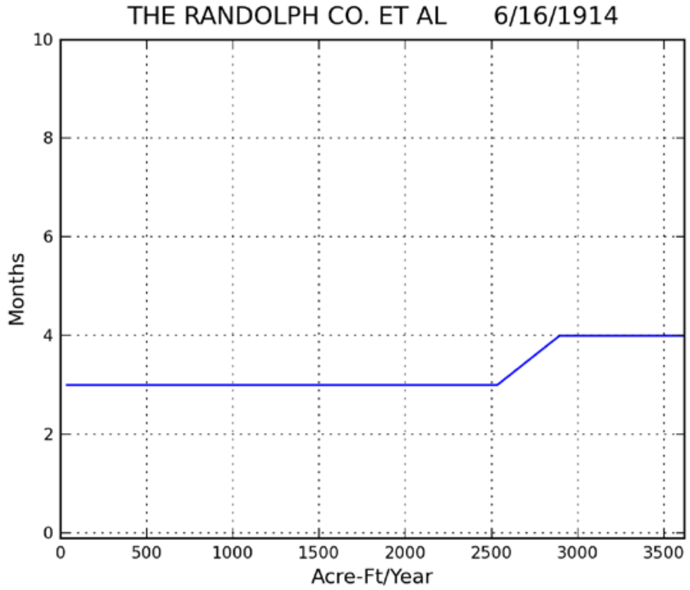

REX C BAILEY JR ET AL 10/16/1985
Reliability (%)
Acre-Ft/Year


TIGNER IRRIGATION CO. 5/9/1986
Reliability (%)
Acre-Ft/Year

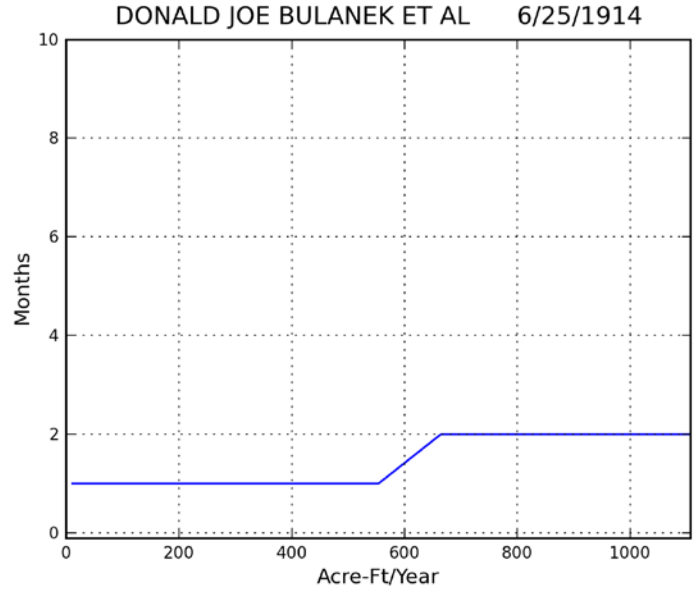

JOHN D VIEMAN ET AL 8/29/1989
Reliability (%)
Acre-Ft/Year


UNITED STATES DEPT OF ENERGY 7/14/2000
Reliability (%)
100
95
90
85
80
75
0
10000
20000
30000
40000
50000
Acre-Ft/Year

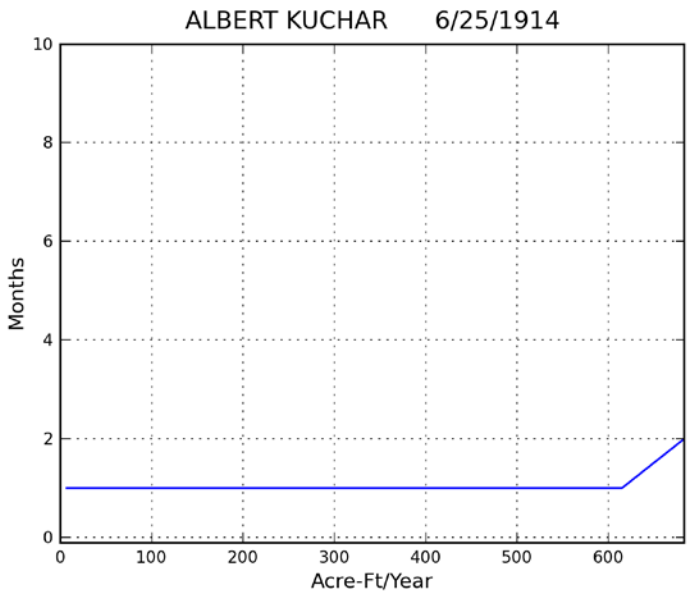
Appendix B – Consecutive Months less than Target Diversion



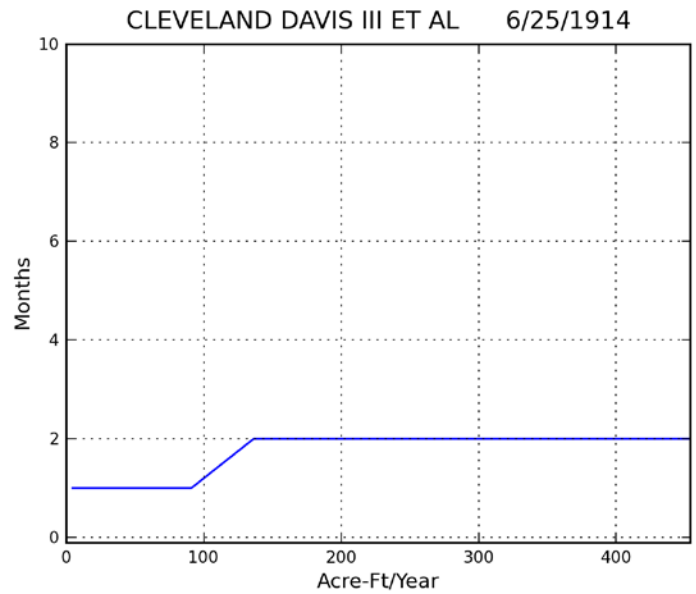
THE RANDOLPH CO. ET AL 6/16/1914
Months
Acre-Ft/Year
0
2
4
6
8
10
0
500
1000
1500
2000
2500
3000
3500



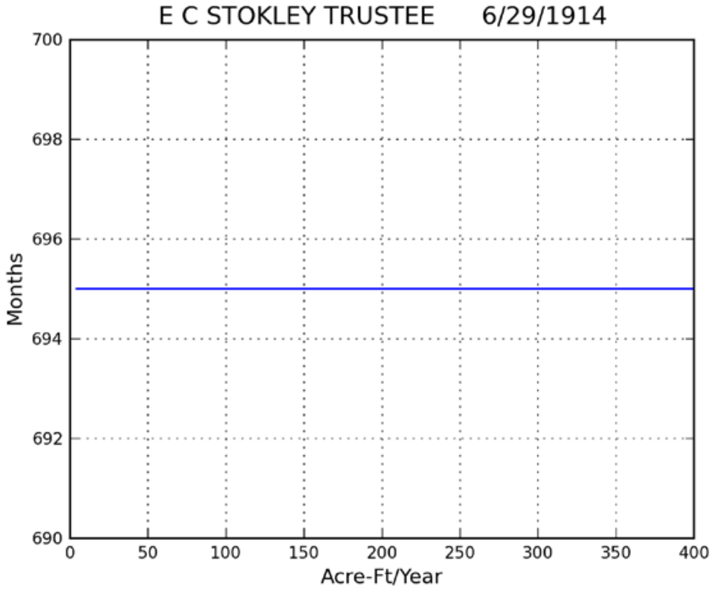
DONALD JOE BULANEK ET AL 6/25/1914
Months
Acre-Ft/Year
0
2
4
6
8
10
0
200
400
600
800
1000

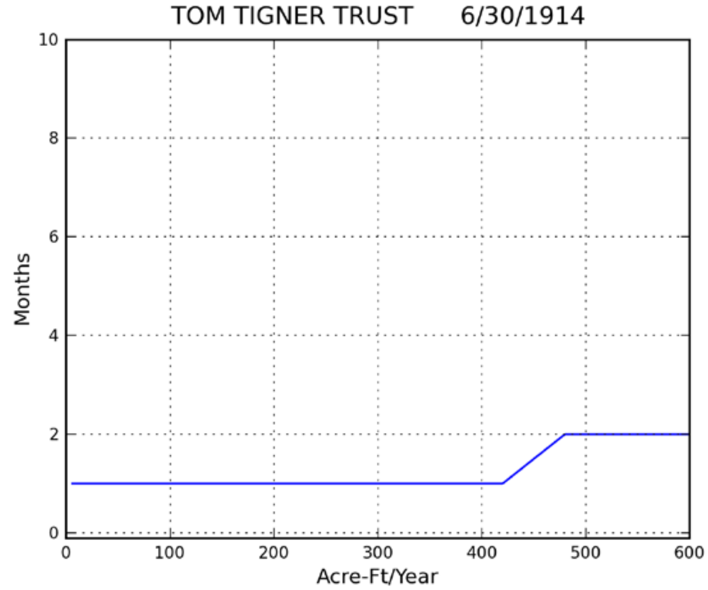


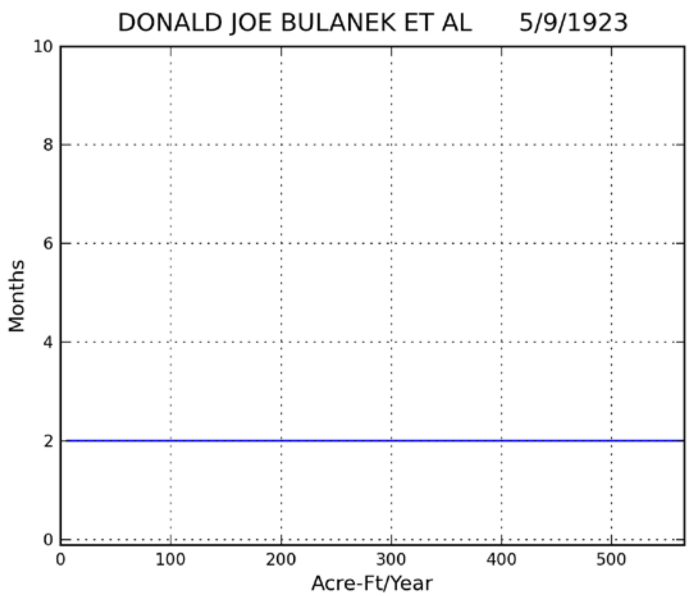
ALBERT KUCHAR 6/25/1914
Months
Acre-Ft/Year
0
2
4
6
8
10
0
100
200
300
400
500
600

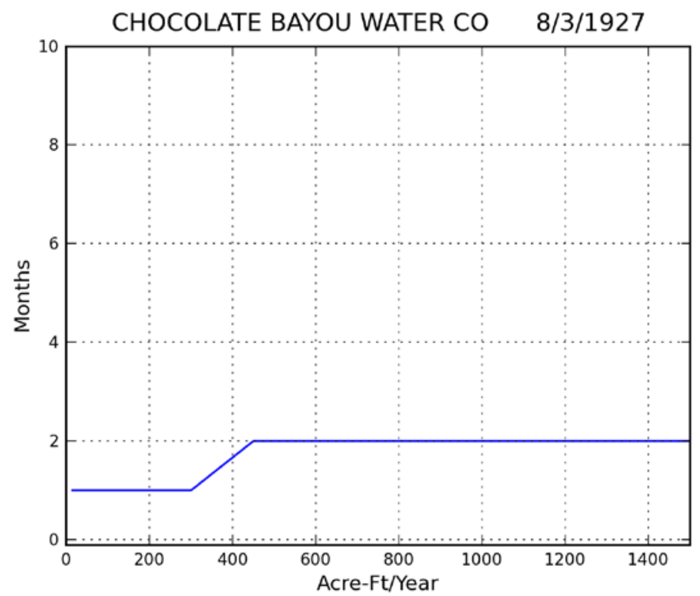


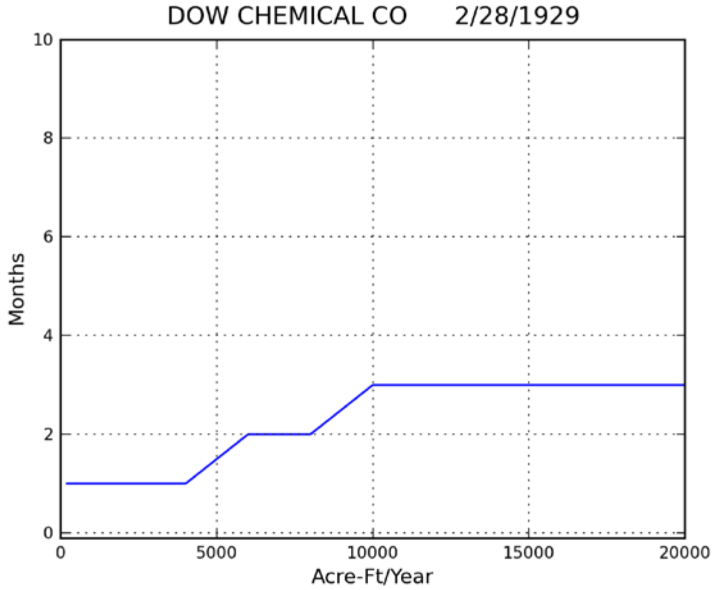
CLEVELAND DAVIS III ET AL 6/25/1914
Months
Acre-Ft/Year
0
2
4
6
8
10
0
100
200
300
400

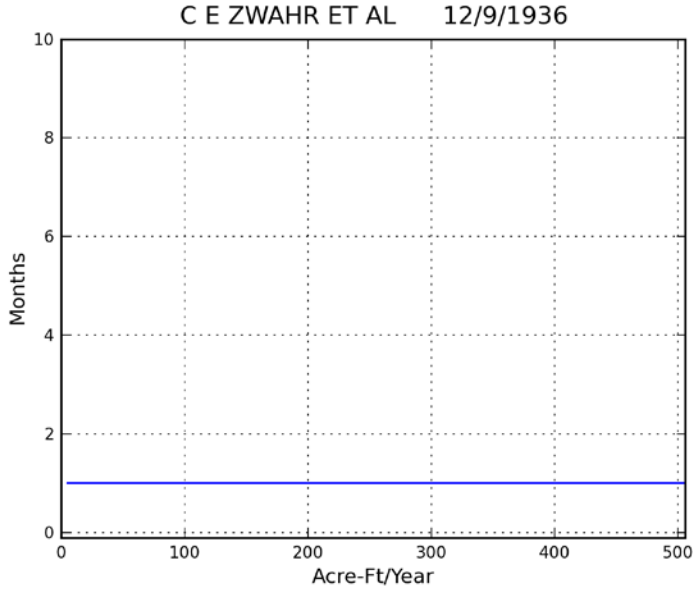

E C STOKLEY TRUSTEE 6/29/1914
Months
700
698
696
694
692
690
0
50
100
150
200
250
300
350
400
Acre-Ft/Year

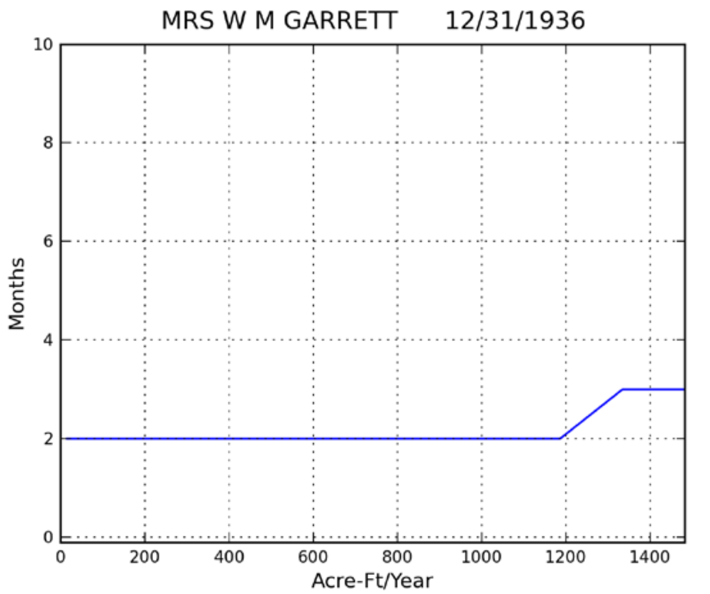

TOM TIGNER TRUST 6/30/1914
Months
10
8
6
4
2
0
0
100
200
300
400
500
600
Acre-Ft/Year

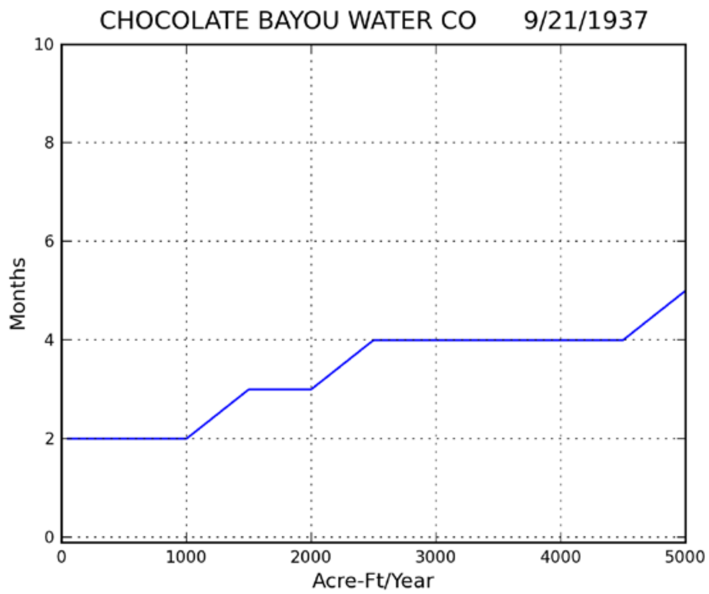

DONALD JOE BULANEK ET AL 5/9/1923
Months
10
8
6
4
2
0
0
100
200
300
400
500
Acre-Ft/Year

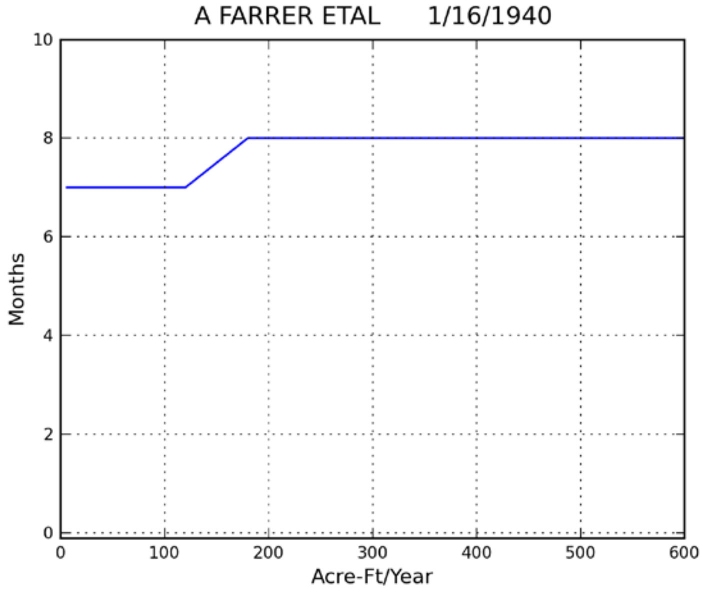

CHOCOLATE BAYOU WATER CO 8/3/1927
Months
10
8
6
4
2
0
0
200
400
600
800
1000
1200
1400
Acre-Ft/Year

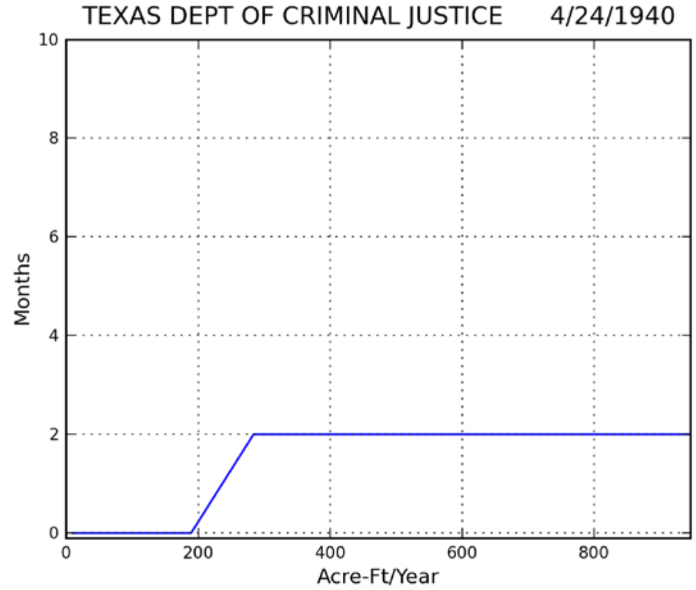

DOW CHEMICAL CO 2/28/1929
Months
Acre-Ft/Year
0
2
4
6
8
10
0
5000
10000
15000
20000

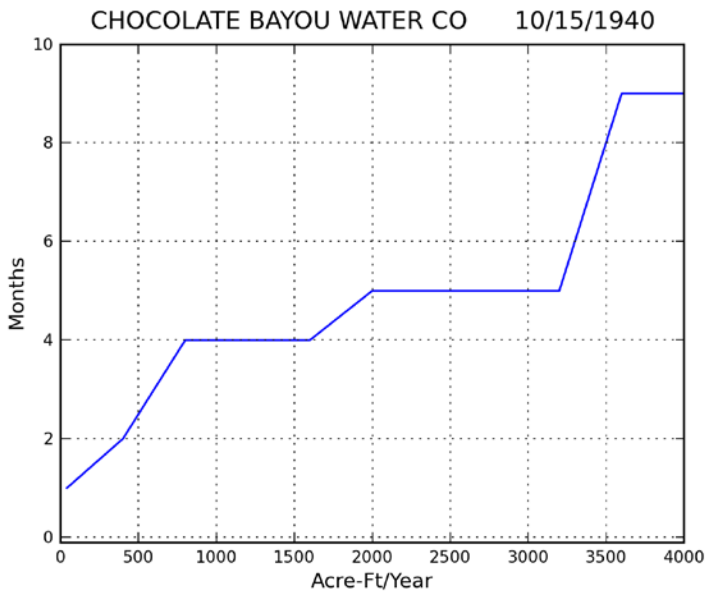

C E ZWAHR ET AL 12/9/1936
Months
Acre-Ft/Year
0
2
4
6
8
10
0
100
200
300
400
500

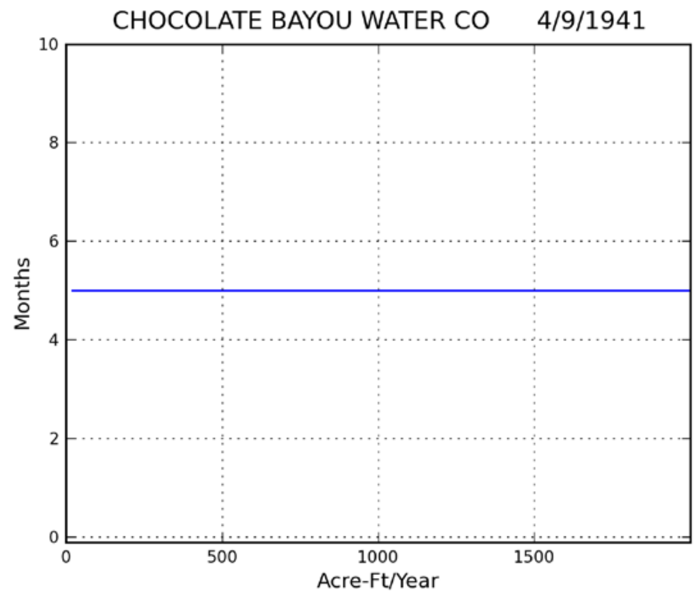

MRS W M GARRETT 12/31/1936
Months
Acre-Ft/Year
0
2
4
6
8
10
0
200
400
600
800
1000
1200
1400

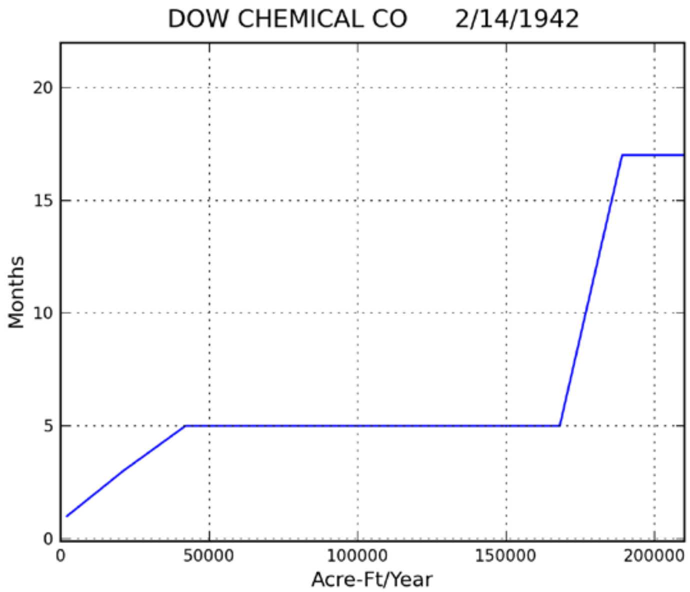

CHOCOLATE BAYOU WATER CO 9/21/1937
Months
Acre-Ft/Year
0
2
4
6
8
10
0
1000
2000
3000
4000
5000

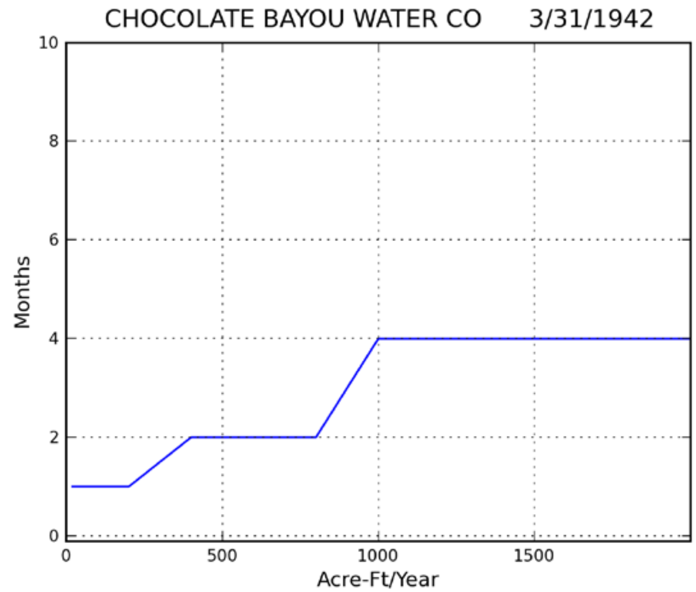

A FARRER ETAL 1/16/1940
Months
Acre-Ft/Year
0
2
4
6
8
10
0
100
200
300
400
500
600

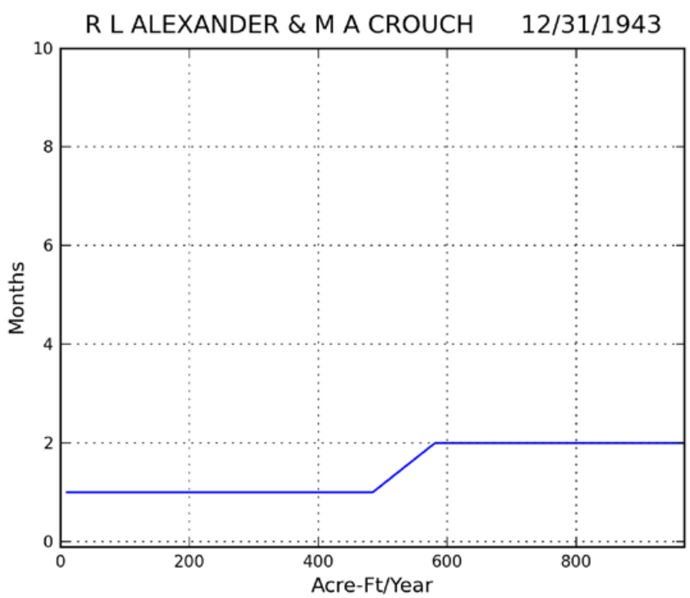

TEXAS DEPT OF CRIMINAL JUSTICE 4/24/1940
Months
Acre-Ft/Year
0
2
4
6
8
10
0
200
400
600
800

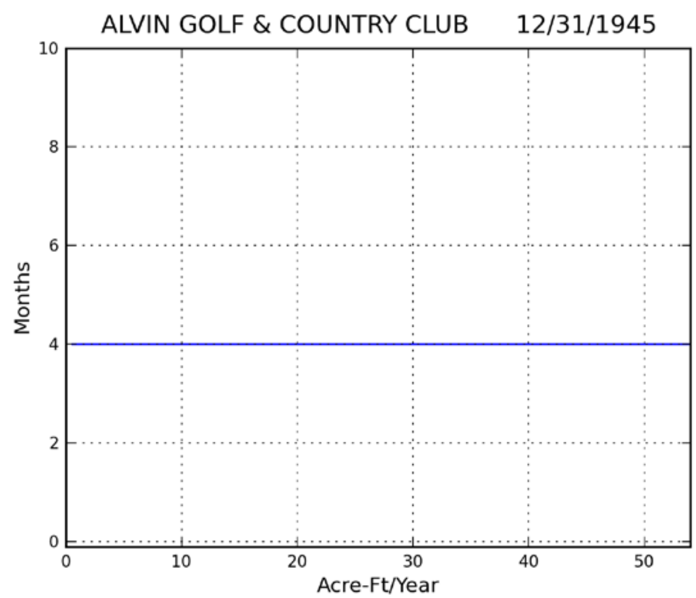

CHOCOLATE BAYOU WATER CO 10/15/1940
Months
Acre-Ft/Year
0
2
4
6
8
10
0
500
1000
1500
2000
2500
3000
3500
4000

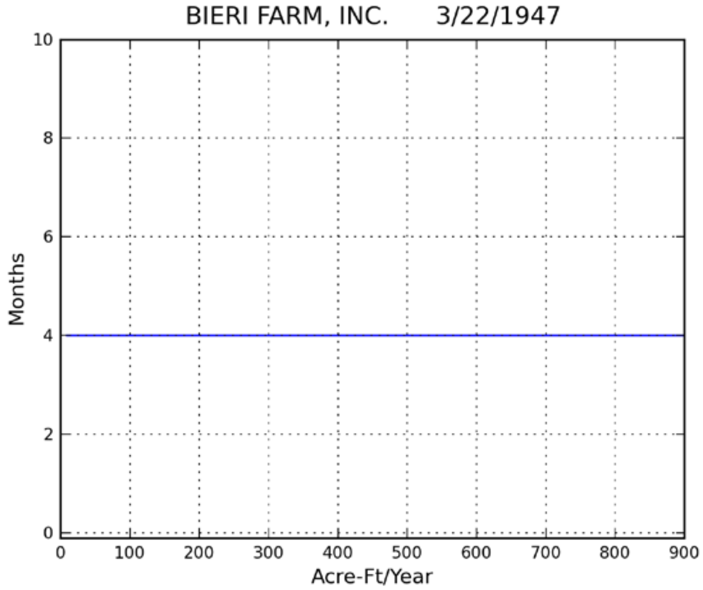

CHOCOLATE BAYOU WATER CO 4/9/1941
Months
Acre-Ft/Year
0
2
4
6
8
10
0
500
1000
1500

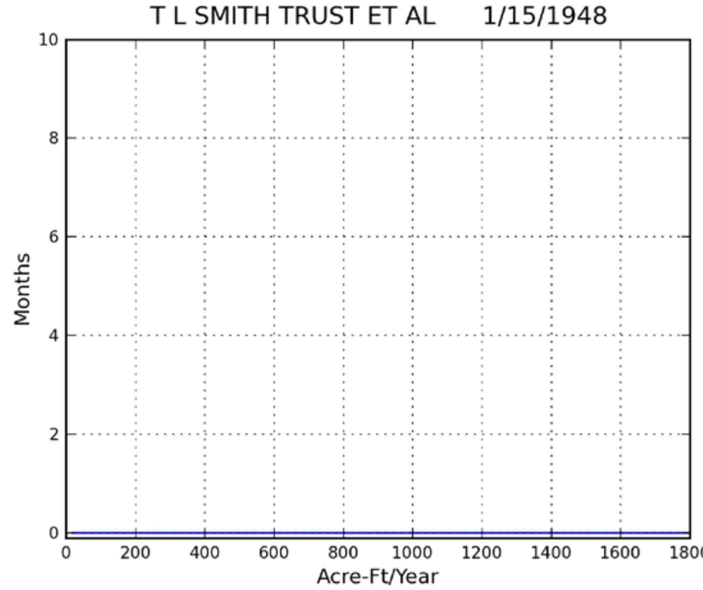

DOW CHEMICAL CO 2/14/1942
Months
Acre-Ft/Year
0
5
10
15
20
50000
100000
150000
200000

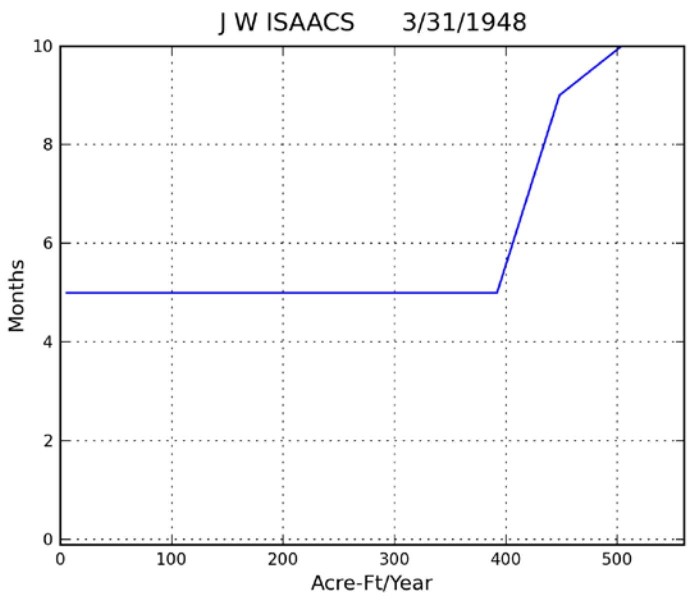

CHOCOLATE BAYOU WATER CO 3/31/1942
Months
Acre-Ft/Year
0
2
4
6
8
10
500
1000
1500

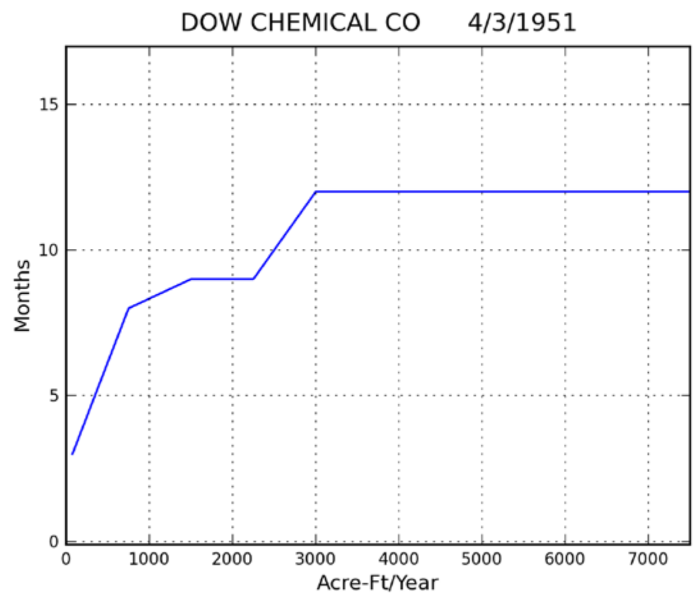

R L ALEXANDER & M A CROUCH 12/31/1943
Months
Acre-Ft/Year
0
2
4
6
8
10
200
400
600
800

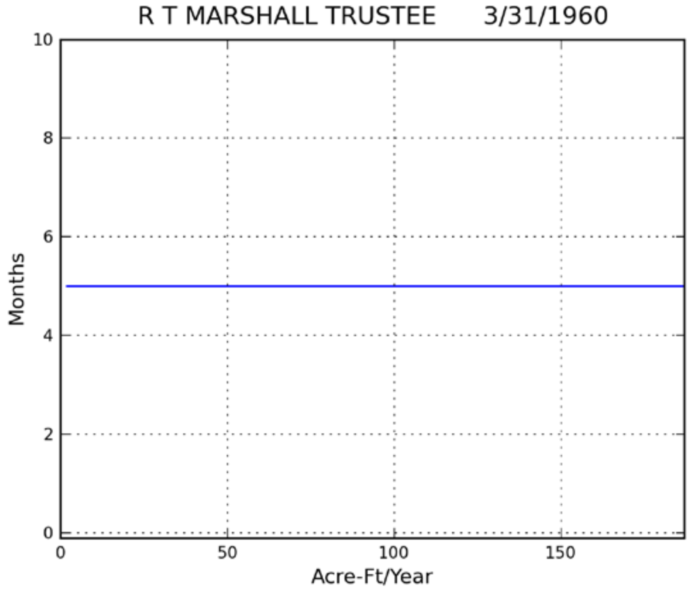

ALVIN GOLF & COUNTRY CLUB 12/31/1945
Months
Acre-Ft/Year
0
2
4
6
8
10
20
30
40
50

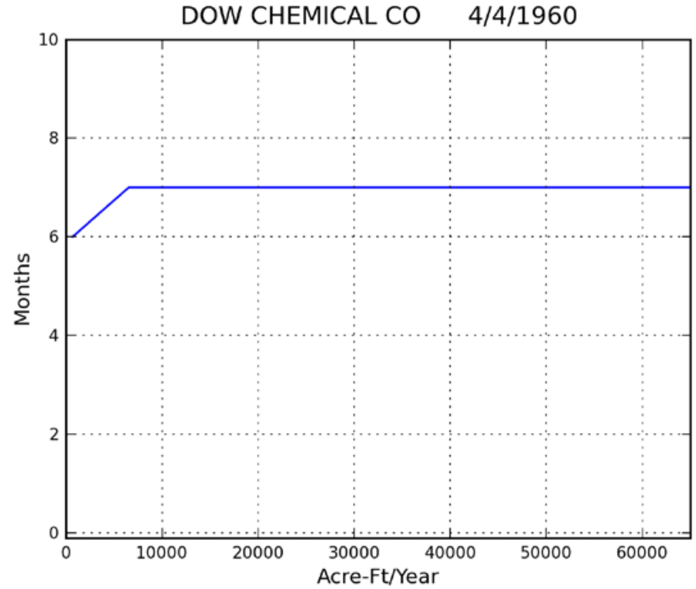

BIERI FARM, INC. 3/22/1947
Months
Acre-Ft/Year

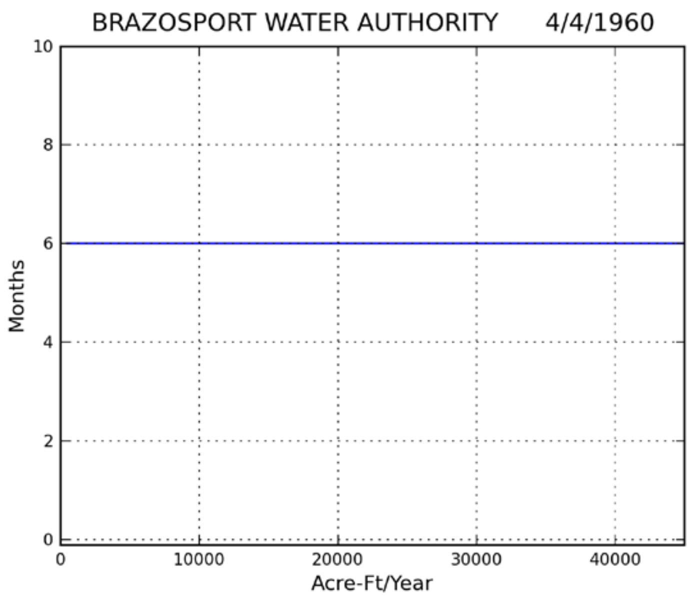

T L SMITH TRUST ET AL 1/15/1948
Months
Acre-Ft/Year

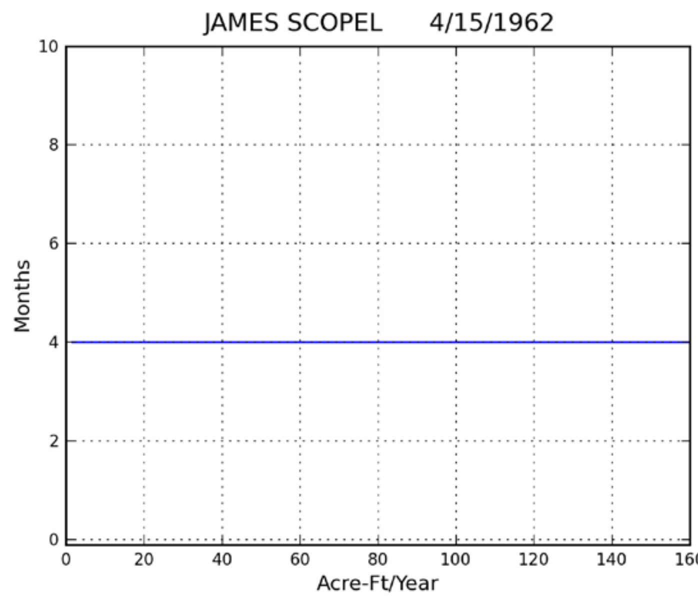

J W ISAACS 3/31/1948
Months
Acre-Ft/Year

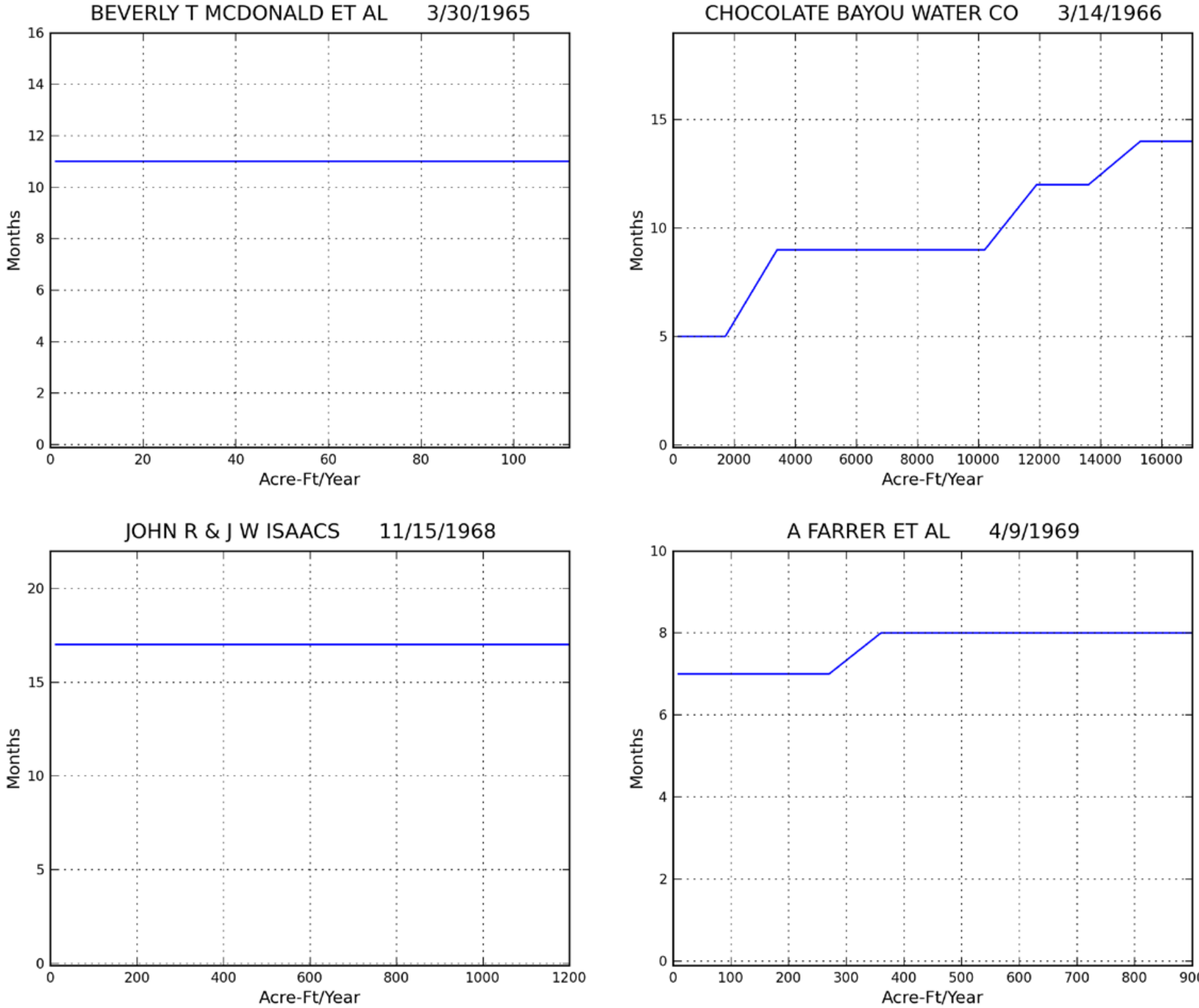

DOW CHEMICAL CO 4/3/1951
Months
Acre-Ft/Year

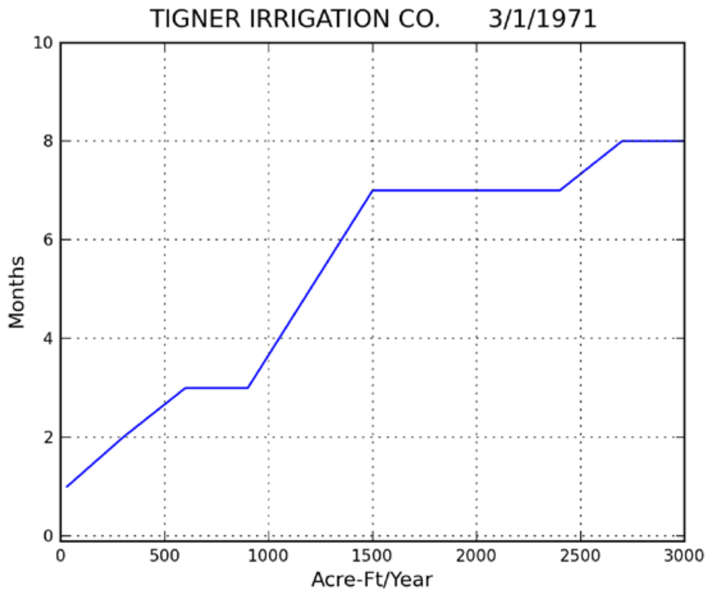

R T MARSHALL TRUSTEE 3/31/1960
Months
Acre-Ft/Year
0
2
4
6
8
10
0
50
100
150

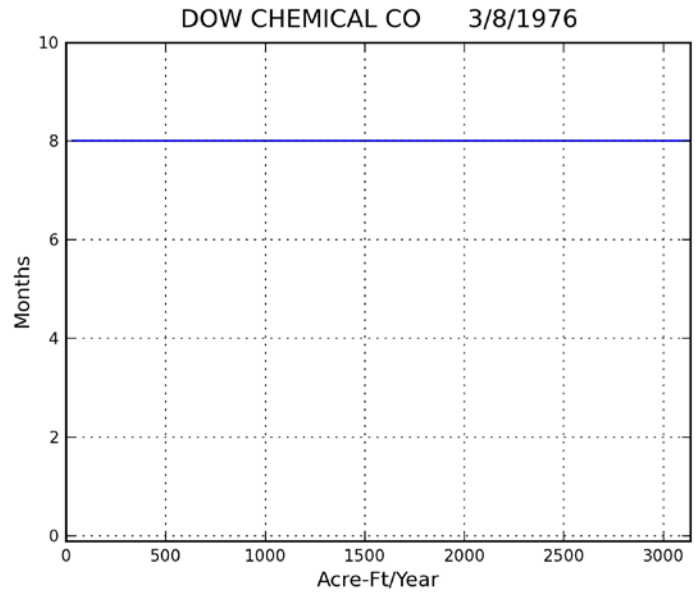

DOW CHEMICAL CO 4/4/1960
Months
Acre-Ft/Year
0
2
4
6
8
10
0
10000
20000
30000
40000
50000
60000

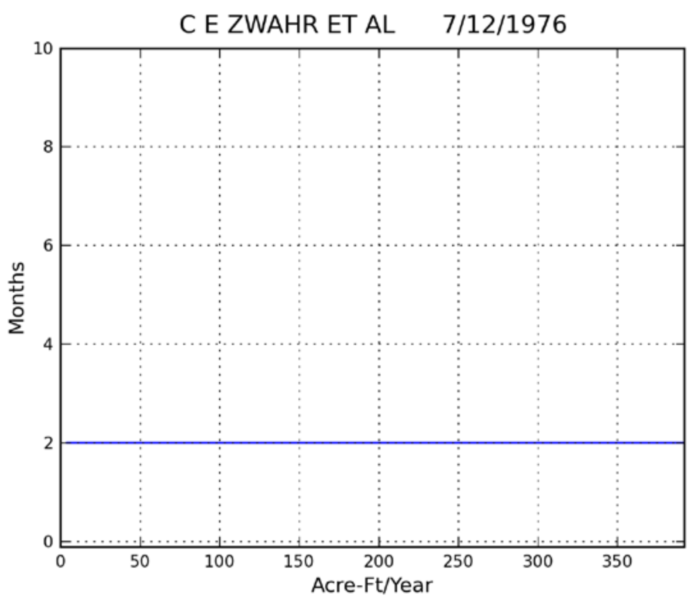

BRAZOSPORT WATER AUTHORITY 4/4/1960
Months
Acre-Ft/Year
0
2
4
6
8
10
0
10000
20000
30000
40000

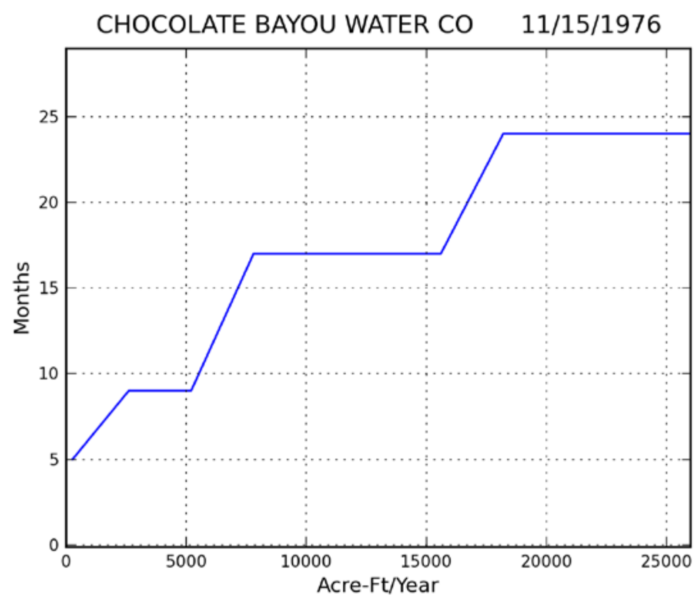

JAMES SCOPEL 4/15/1962
Months
Acre-Ft/Year
0
2
4
6
8
10
0
20
40
60
80
100
120
140
160

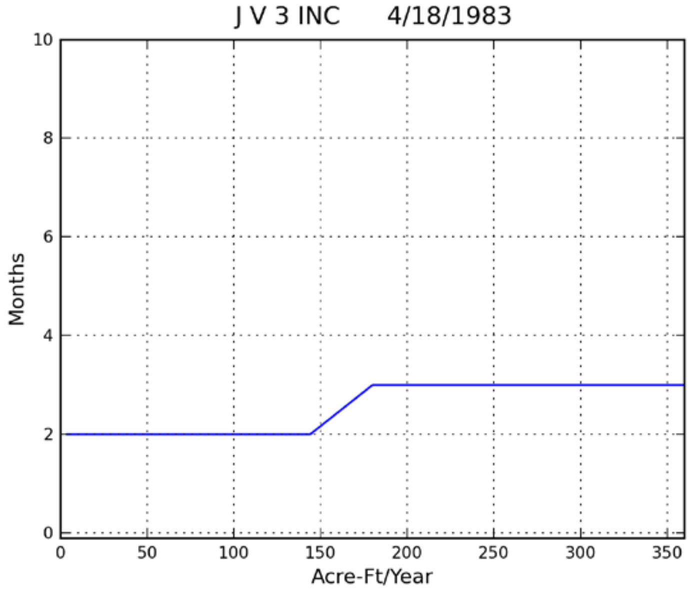

BEVERLY T MCDONALD ET AL 3/30/1965
Months
Acre-Ft/Year
CHOCOLATE BAYOU WATER CO 3/14/1966
Months
Acre-Ft/Year
JOHN R & J W ISAACS 11/15/1968
Months
Acre-Ft/Year
A FARRER ET AL 4/9/1969
Months
Acre-Ft/Year

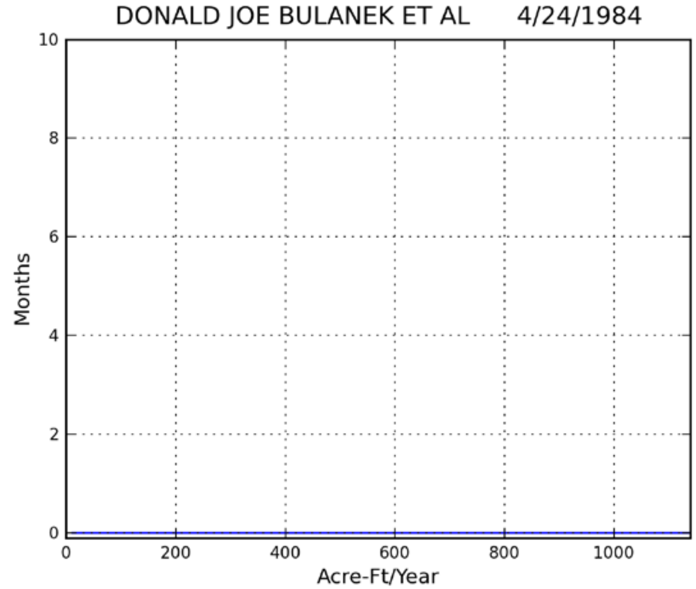

TIGNER IRRIGATION CO. 3/1/1971
Months
0
2
4
6
8
10
0
500
1000
1500
2000
2500
3000
Acre-Ft/Year

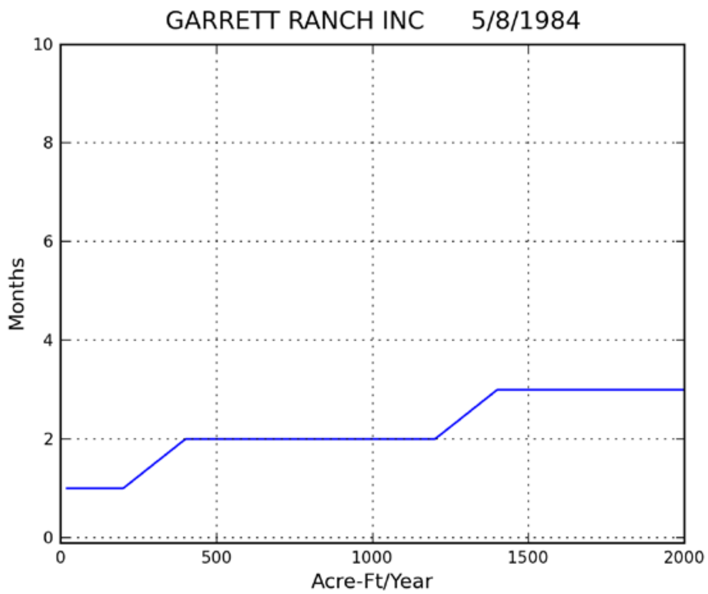

DOW CHEMICAL CO 3/8/1976
Months
0
2
4
6
8
10
0
500
1000
1500
2000
2500
3000
Acre-Ft/Year

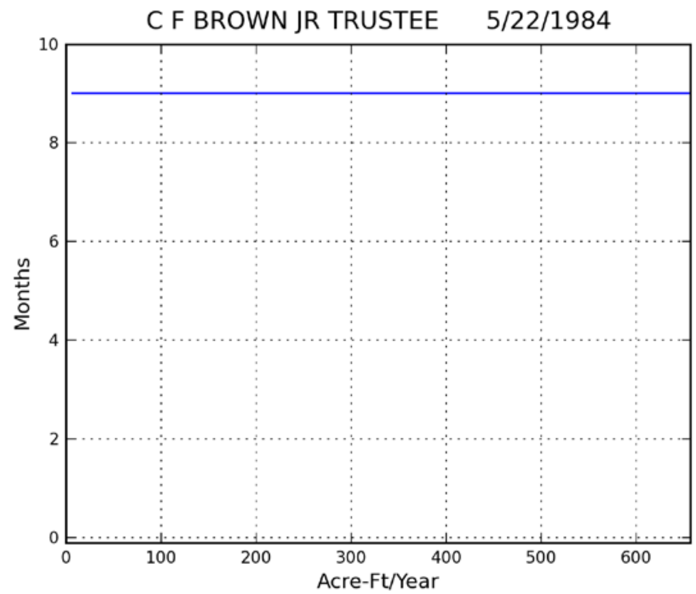

C E ZWAHR ET AL 7/12/1976
Months
0
2
4
6
8
10
0
50
100
150
200
250
300
350
Acre-Ft/Year

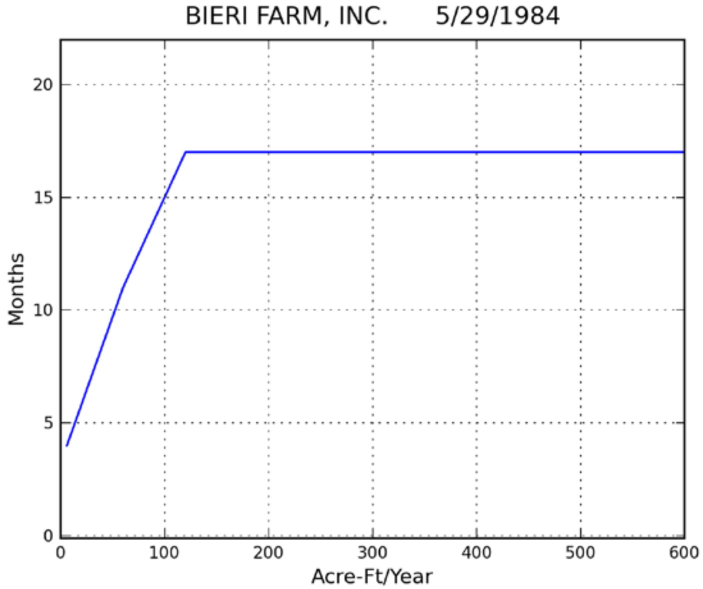

CHOCOLATE BAYOU WATER CO 11/15/1976
Months
0
5
10
15
20
25
0
5000
10000
15000
20000
25000
Acre-Ft/Year


J V 3 INC 4/18/1983
Months
Acre-Ft/Year
0
2
4
6
8
10
0
50
100
150
200
250
300
350

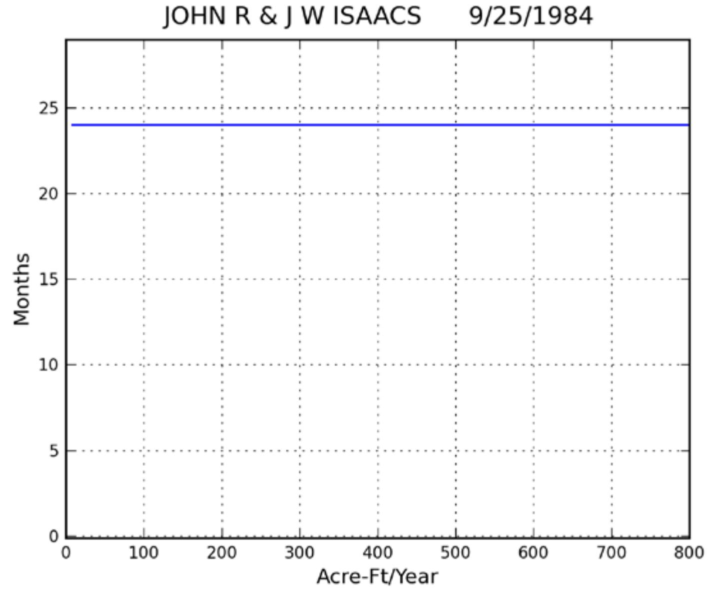

DONALD JOE BULANEK ET AL 4/24/1984
Months
Acre-Ft/Year
0
2
4
6
8
10
0
200
400
600
800
1000


GARRETT RANCH INC 5/8/1984
Months
Acre-Ft/Year
0
2
4
6
8
10
0
500
1000
1500
2000

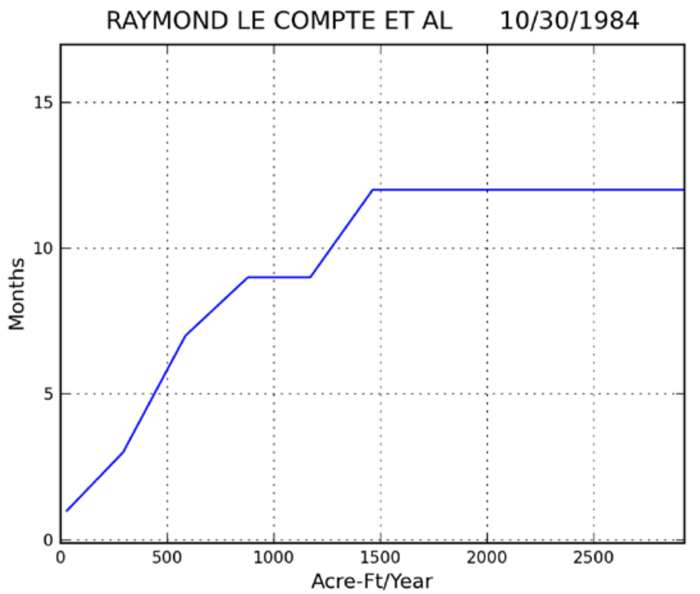

C F BROWN JR TRUSTEE 5/22/1984
Months
Acre-Ft/Year
0
2
4
6
8
10
0
100
200
300
400
500
600



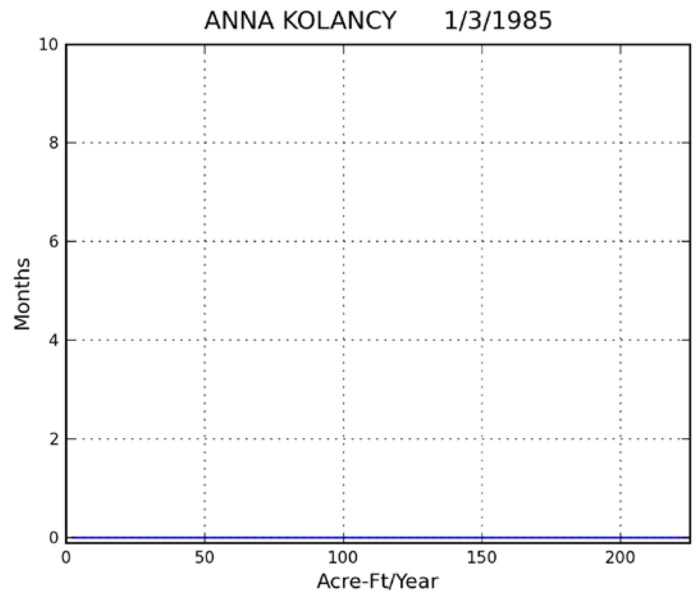
BIERI FARM, INC. 5/29/1984
Months
Acre-Ft/Year
0
5
10
15
20
100
200
300
400
500
600



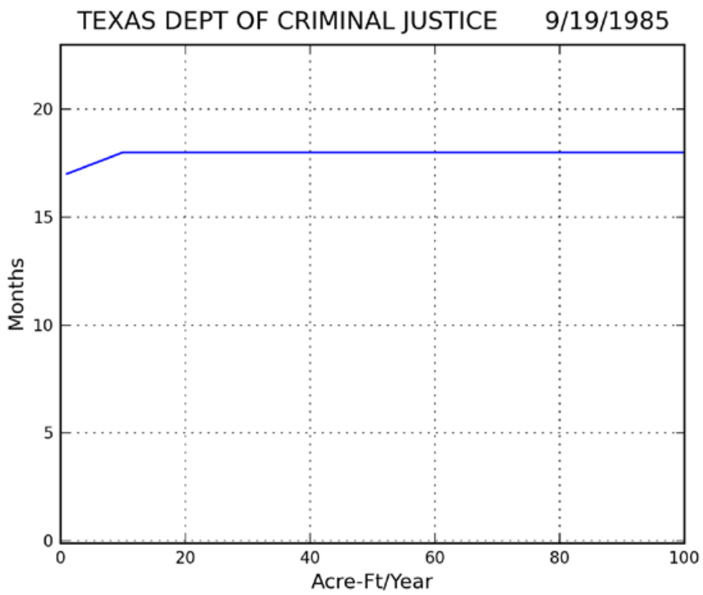
JOHN R & J W ISAACS 9/25/1984
Months
Acre-Ft/Year
0
5
10
15
20
25
100
200
300
400
500
600
700
800

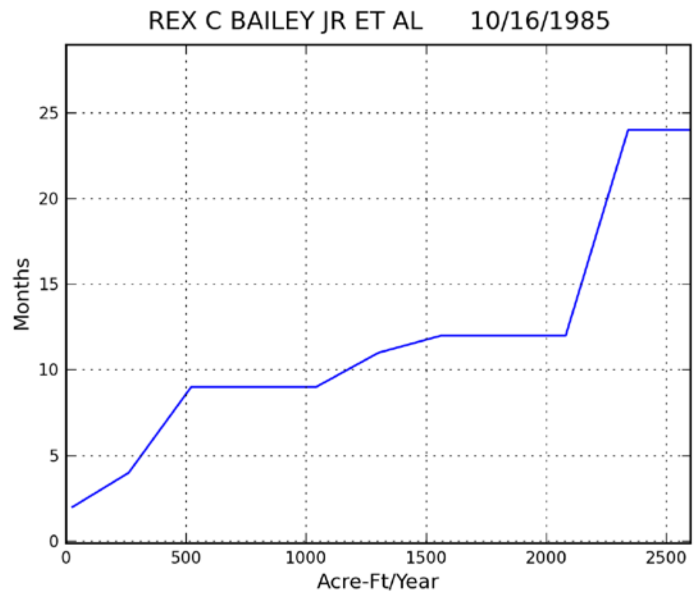


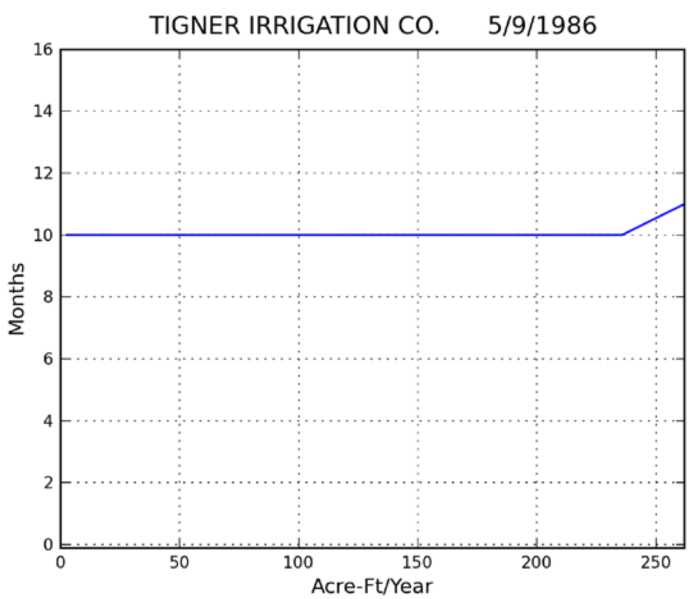
RAYMOND LE COMPTE ET AL 10/30/1984
Months
Acre-Ft/Year
0
5
10
15
500
1000
1500
2000
2500

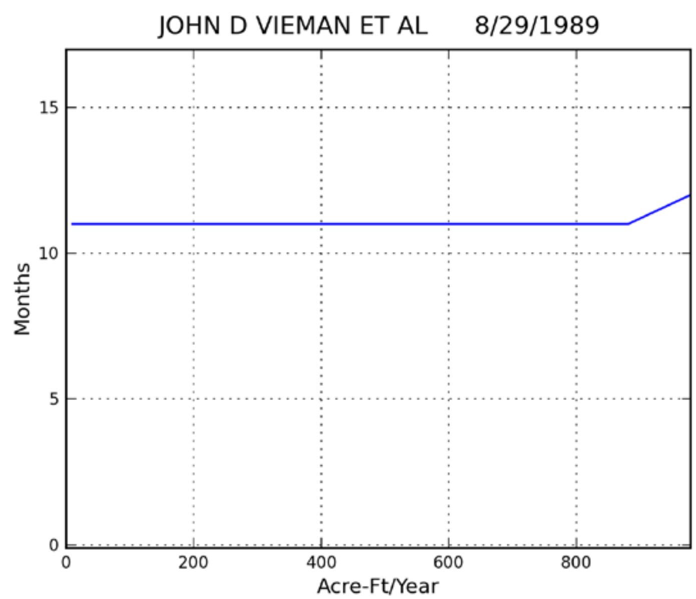


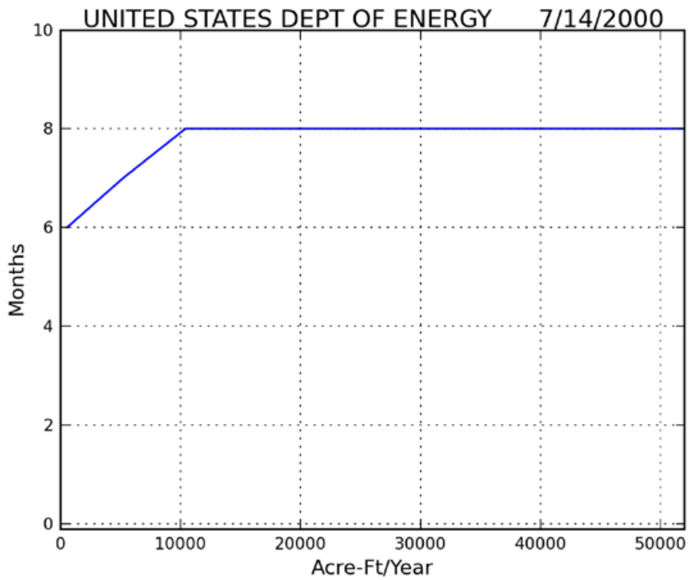
ANNA KOLANCY 1/3/1985
Months
Acre-Ft/Year
0
2
4
6
8
10
50
100
150
200


TEXAS DEPT OF CRIMINAL JUSTICE 9/19/1985
Months
Acre-Ft/Year
0
5
10
15
20
0
20
40
60
80
100

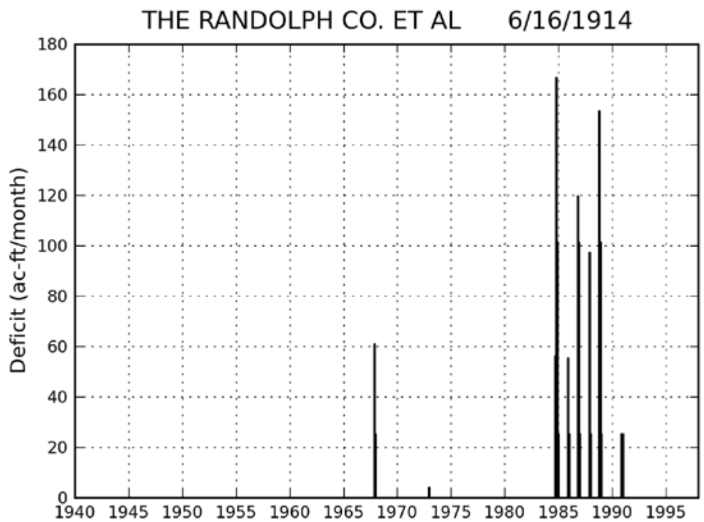

REX C BAILEY JR ET AL 10/16/1985
Months
Acre-Ft/Year
0
5
10
15
20
25
0
500
1000
1500
2000
2500

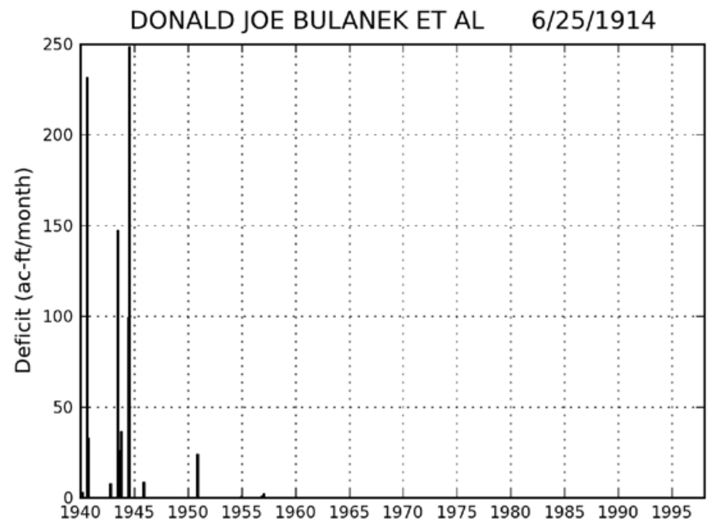

TIGNER IRRIGATION CO. 5/9/1986
Months
Acre-Ft/Year
0
2
4
6
8
10
12
14
16
0
50
100
150
200
250

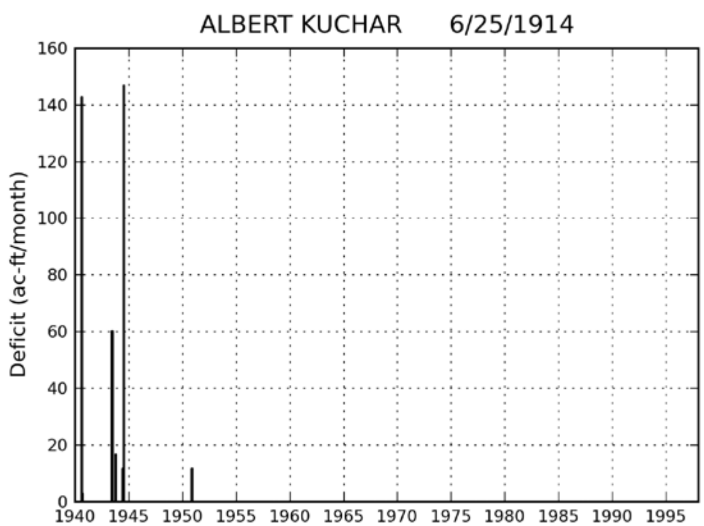

JOHN D VIEMAN ET AL 8/29/1989
Months
Acre-Ft/Year
0
5
10
15
0
200
400
600
800

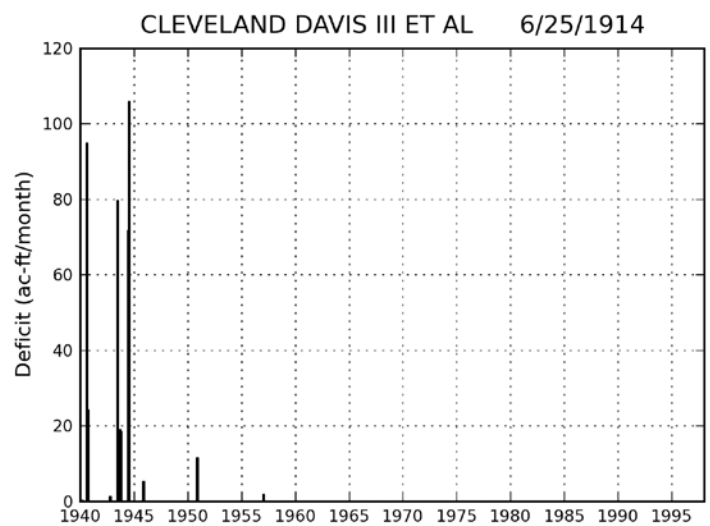

UNITED STATES DEPT OF ENERGY 7/14/2000
Months
Acre-Ft/Year
0
2
4
6
8
10
0
10000
20000
30000
40000
50000

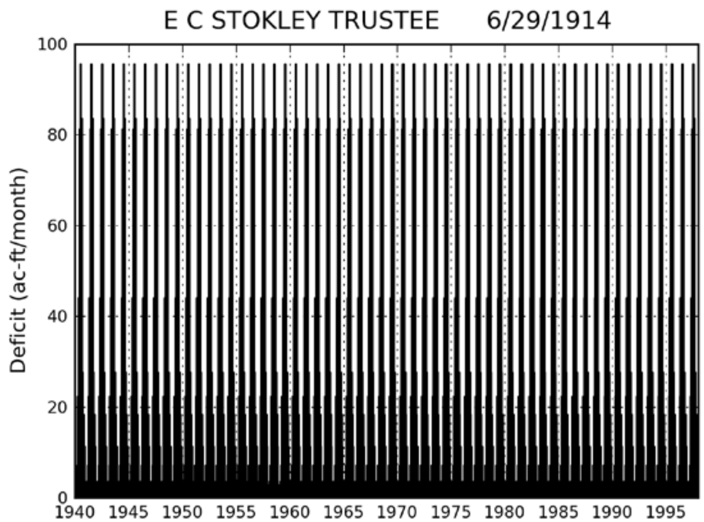
Appendix C – Target Deficits

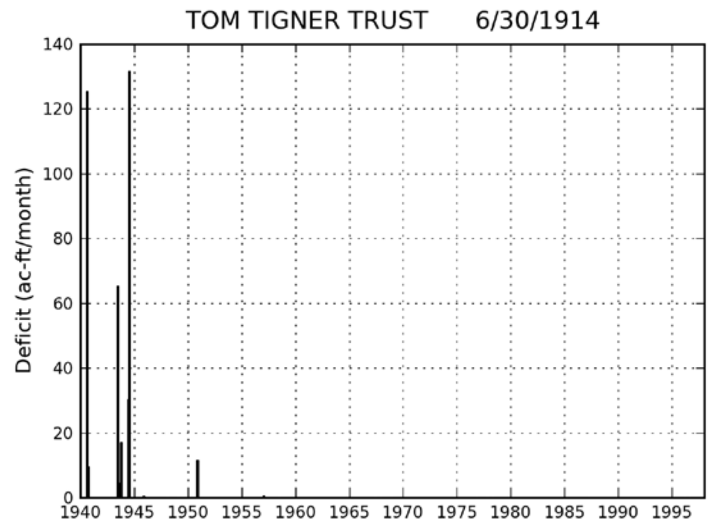

THE RANDOLPH CO. ET AL 6/16/1914
Deficit (ac-ft/month)
0 20 40 60 80 100 120 140 160 180
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

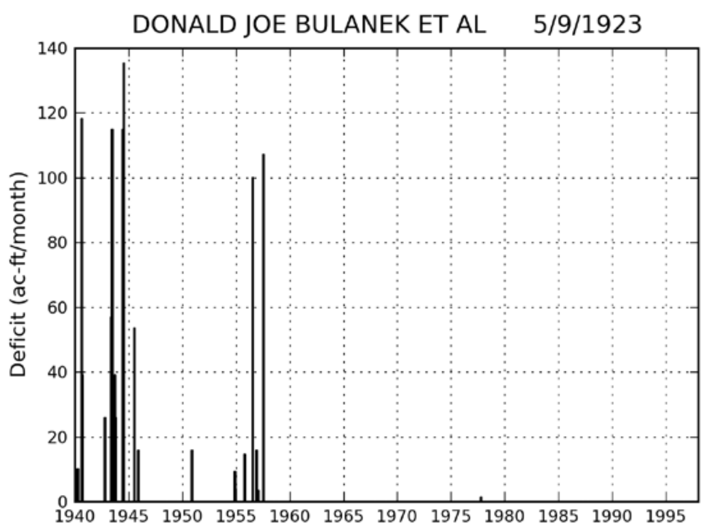

DONALD JOE BULANEK ET AL 6/25/1914
Deficit (ac-ft/month)
0 50 100 150 200 250
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

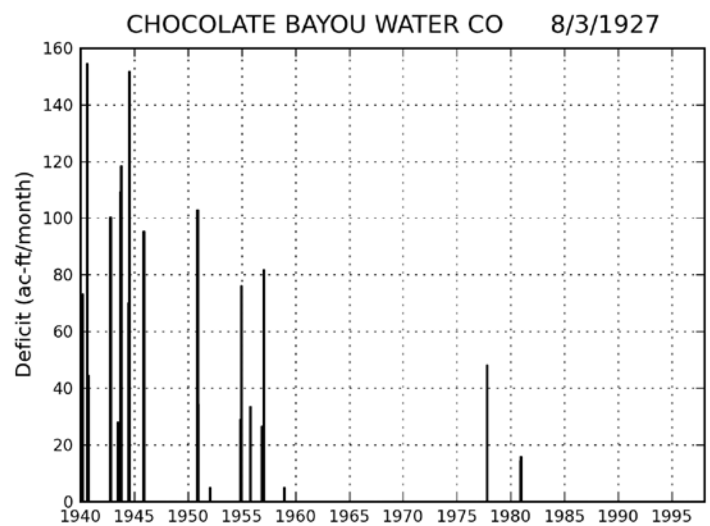

ALBERT KUCHAR 6/25/1914
Deficit (ac-ft/month)
0 20 40 60 80 100 120 140 160
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

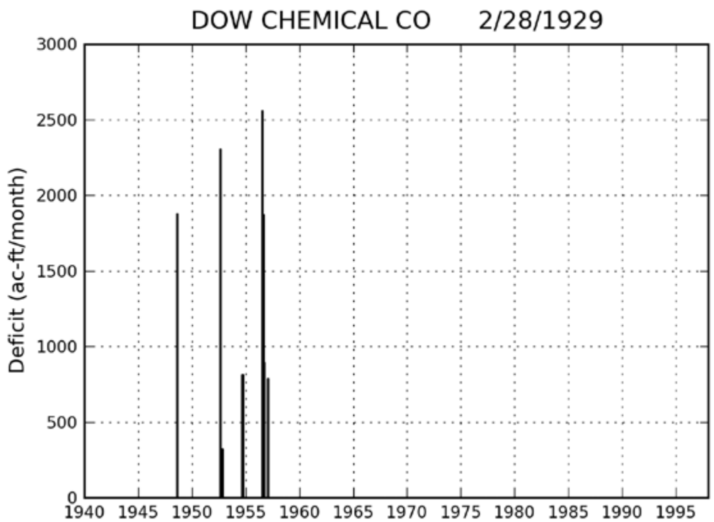

CLEVELAND DAVIS III ET AL 6/25/1914
Deficit (ac-ft/month)
0 20 40 60 80 100 120
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

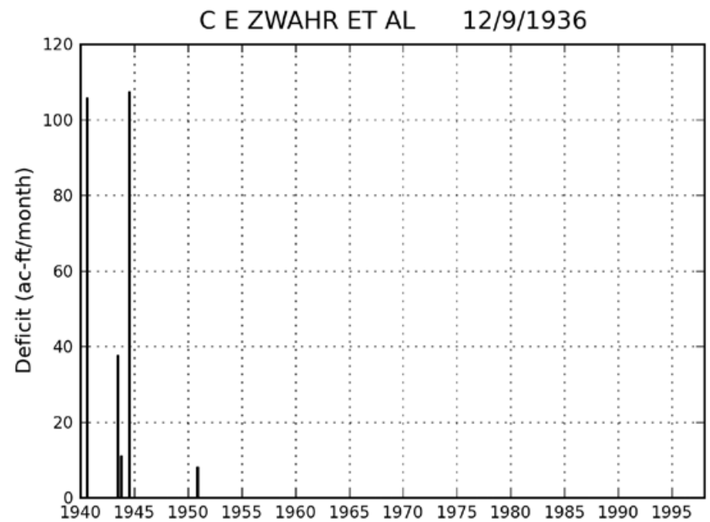

E C STOKLEY TRUSTEE 6/29/1914
Deficit (ac-ft/month)
0
20
40
60
80
100
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

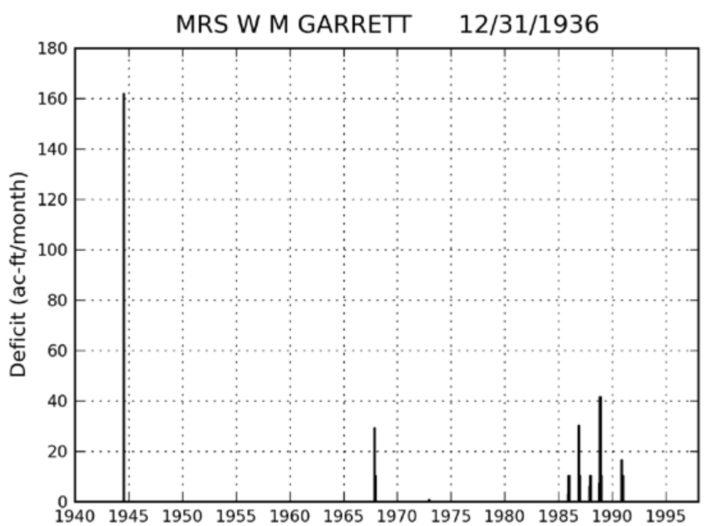

TOM TIGNER TRUST 6/30/1914
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

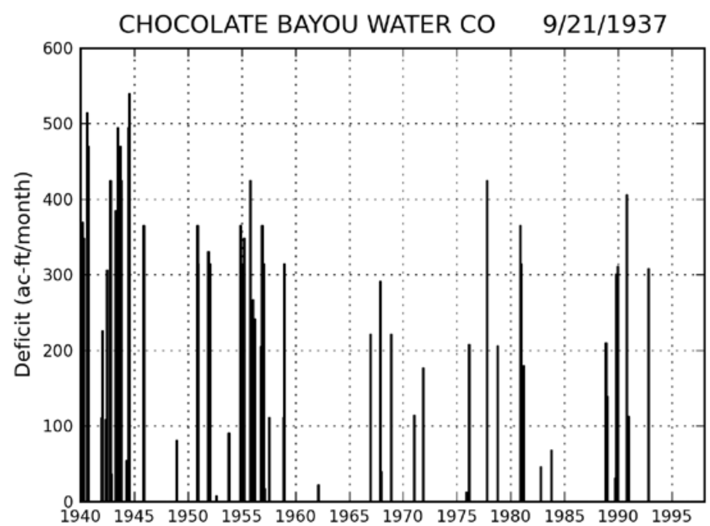

DONALD JOE BULANEK ET AL 5/9/1923
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

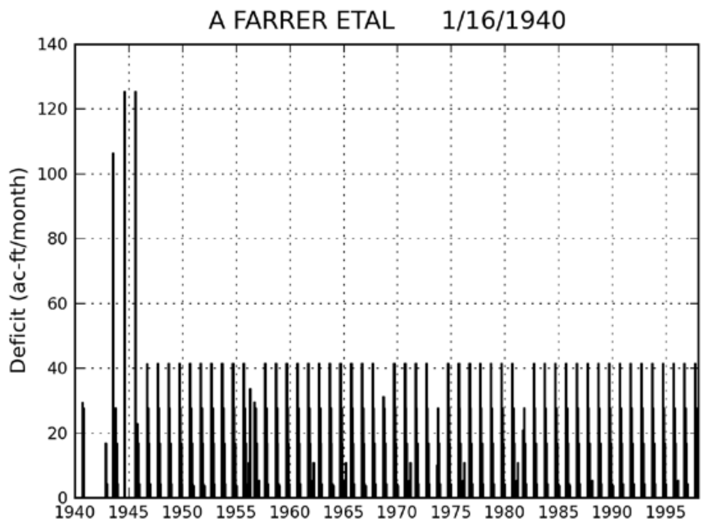

CHOCOLATE BAYOU WATER CO 8/3/1927
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
160
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

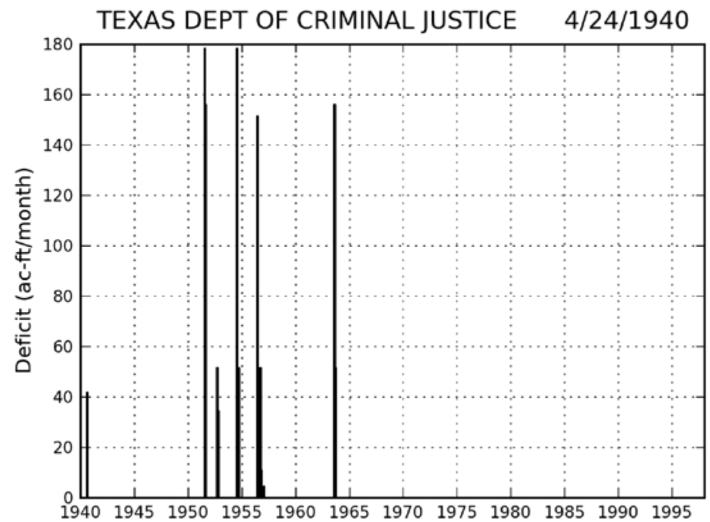

DOW CHEMICAL CO 2/28/1929
Deficit (ac-ft/month)
3000
2500
2000
1500
1000
500
0
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

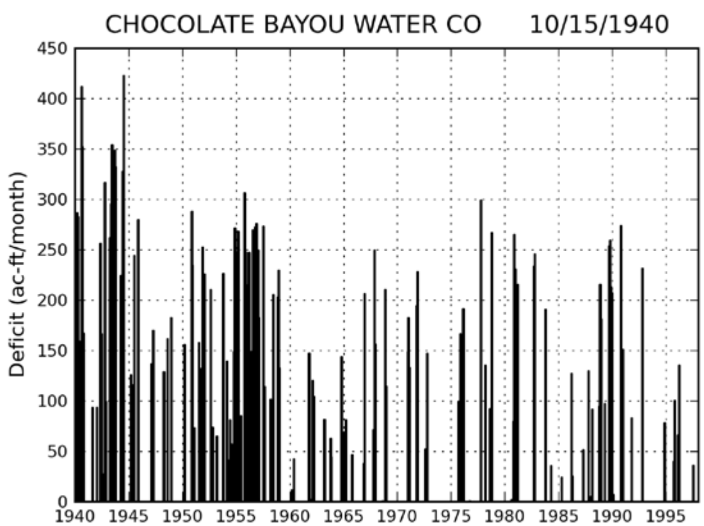

C E ZWAHR ET AL 12/9/1936
Deficit (ac-ft/month)
120
100
80
60
40
20
0
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

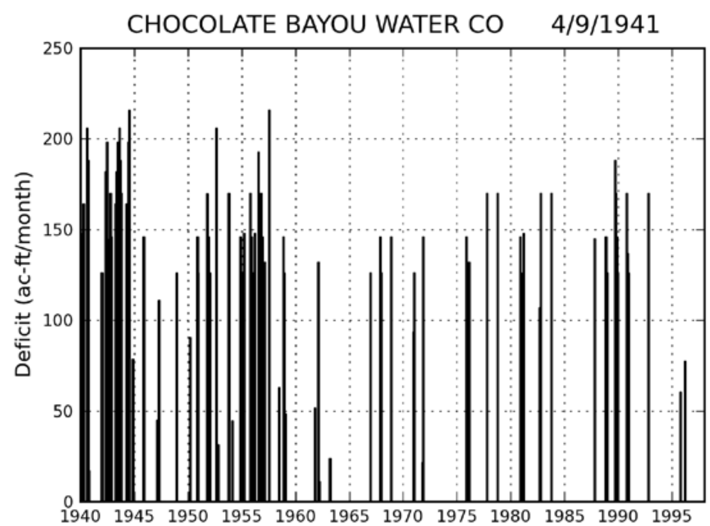

MRS W M GARRETT 12/31/1936
Deficit (ac-ft/month)
180
160
140
120
100
80
60
40
20
0
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

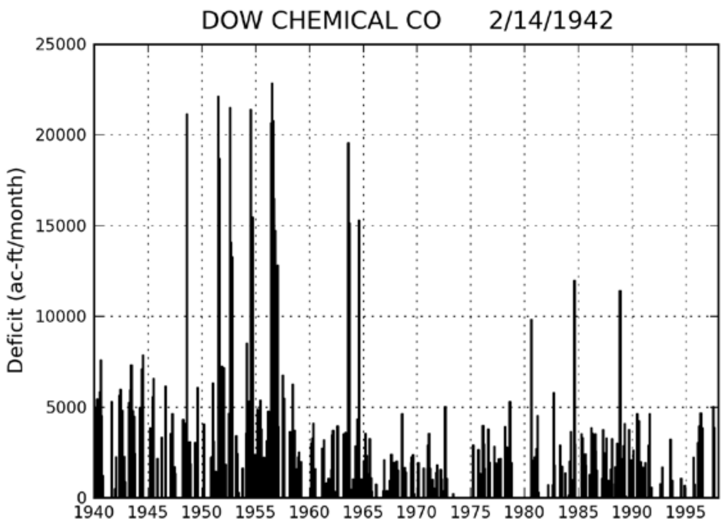

CHOCOLATE BAYOU WATER CO 9/21/1937
Deficit (ac-ft/month)
600
500
400
300
200
100
0
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

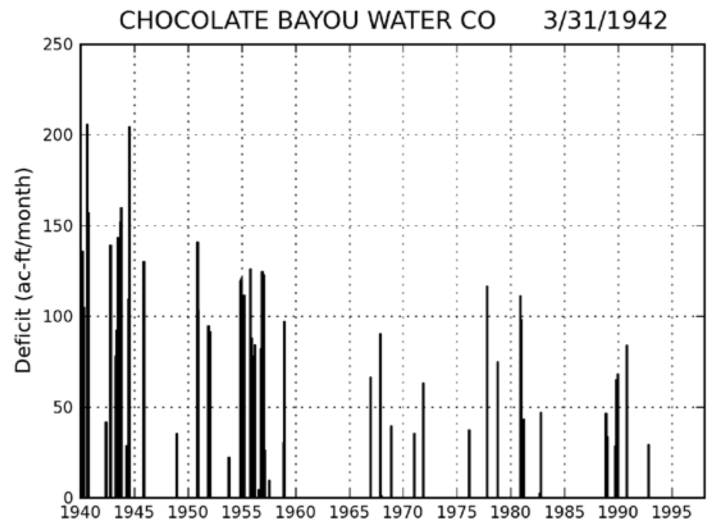

A FARRER ETAL 1/16/1940
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

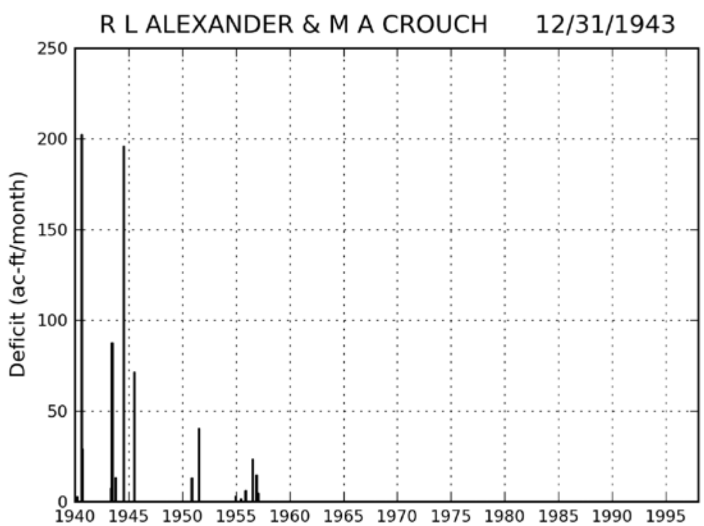

TEXAS DEPT OF CRIMINAL JUSTICE 4/24/1940
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
160
180
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

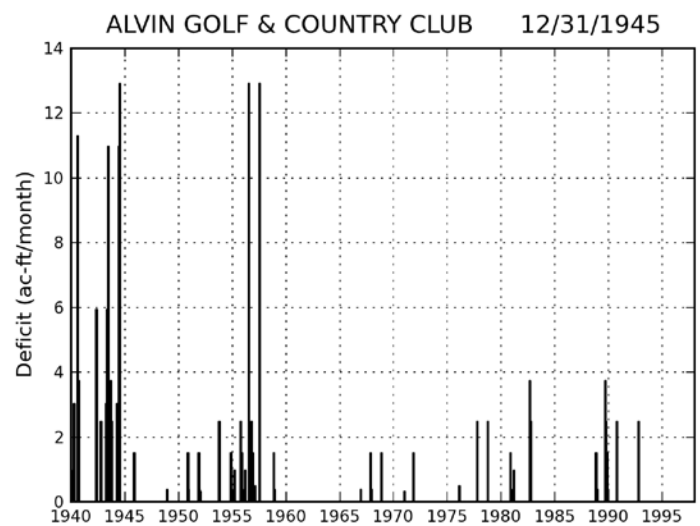

CHOCOLATE BAYOU WATER CO 10/15/1940
Deficit (ac-ft/month)
0
50
100
150
200
250
300
350
400
450
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

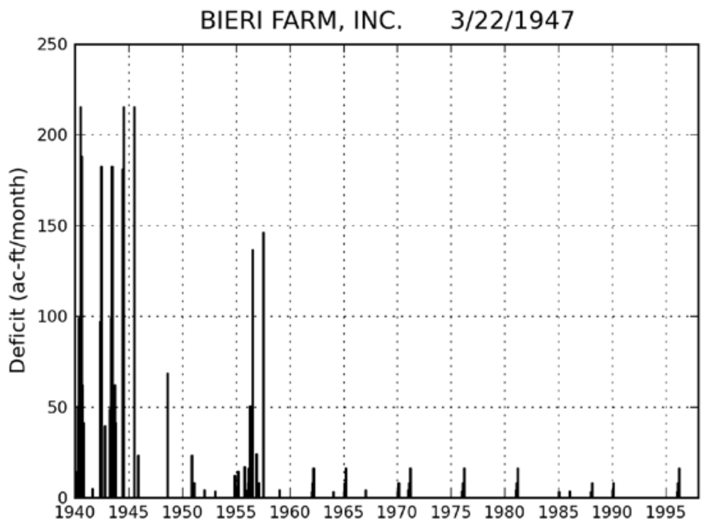

CHOCOLATE BAYOU WATER CO 4/9/1941
Deficit (ac-ft/month)
0
50
100
150
200
250
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

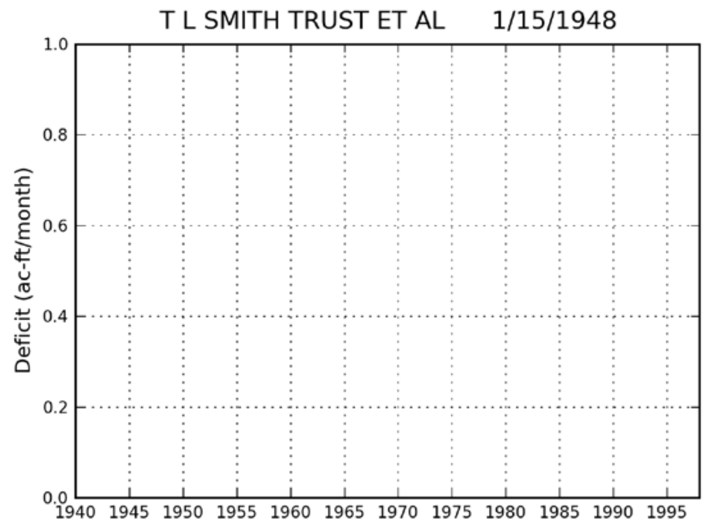

DOW CHEMICAL CO 2/14/1942
Deficit (ac-ft/month)
0
5000
10000
15000
20000
25000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

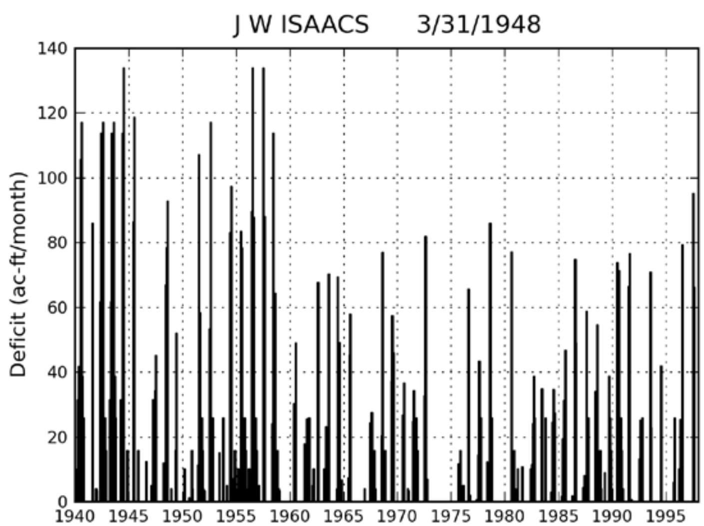

CHOCOLATE BAYOU WATER CO 3/31/1942
Deficit (ac-ft/month)
0
50
100
150
200
250
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

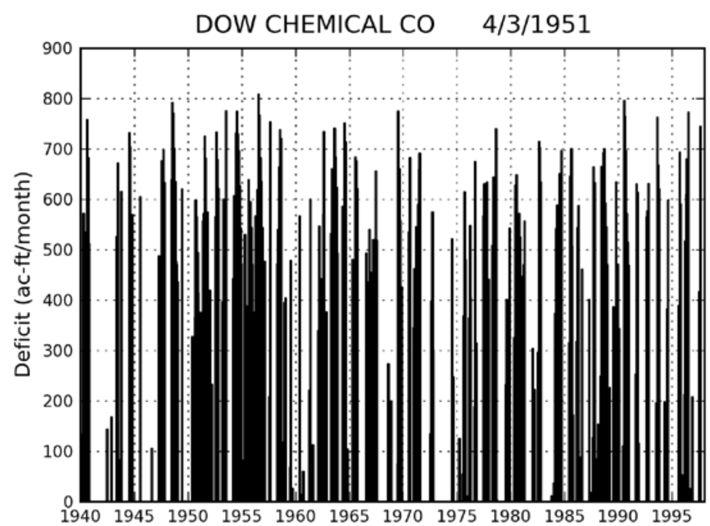

R L ALEXANDER & M A CROUCH 12/31/1943
Deficit (ac-ft/month)
0
50
100
150
200
250
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

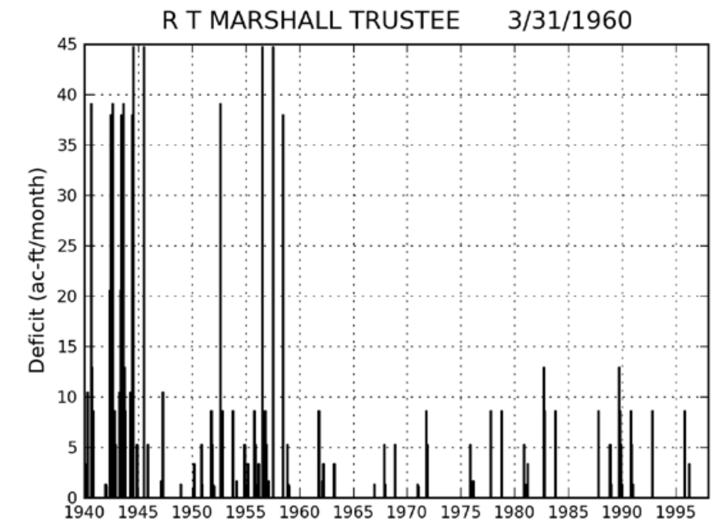

ALVIN GOLF & COUNTRY CLUB 12/31/1945
Deficit (ac-ft/month)
0
2
4
6
8
10
12
14
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

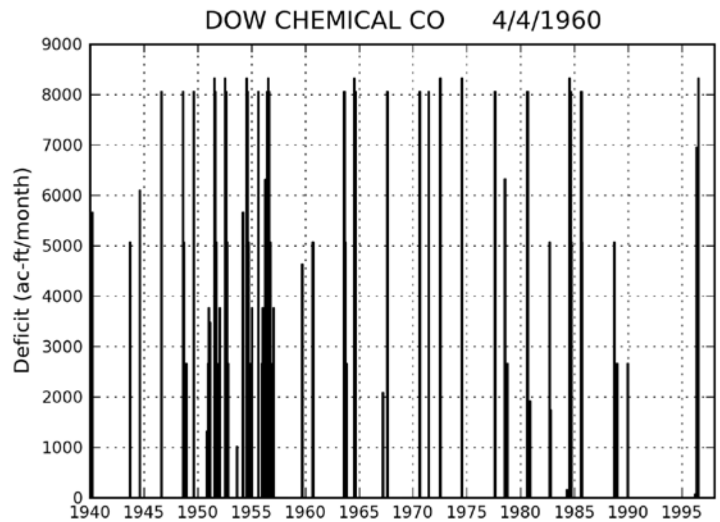

BIERI FARM, INC. 3/22/1947
Deficit (ac-ft/month)
0
50
100
150
200
250
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

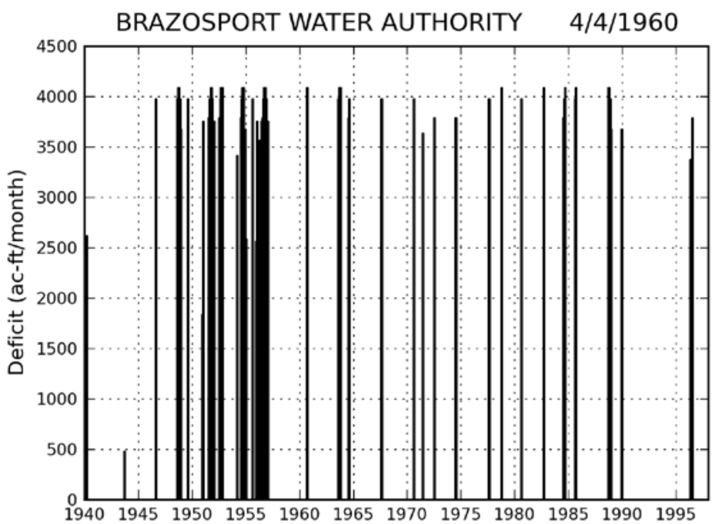

T L SMITH TRUST ET AL 1/15/1948
Deficit (ac-ft/month)
0.0
0.2
0.4
0.6
0.8
1.0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

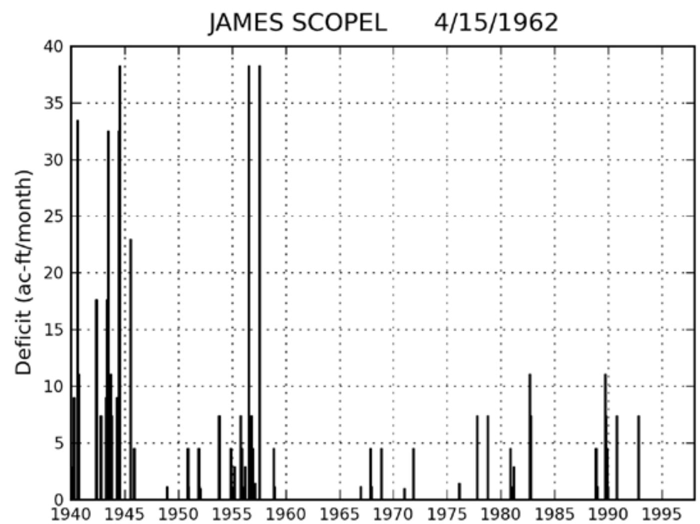

J W ISAACS 3/31/1948
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

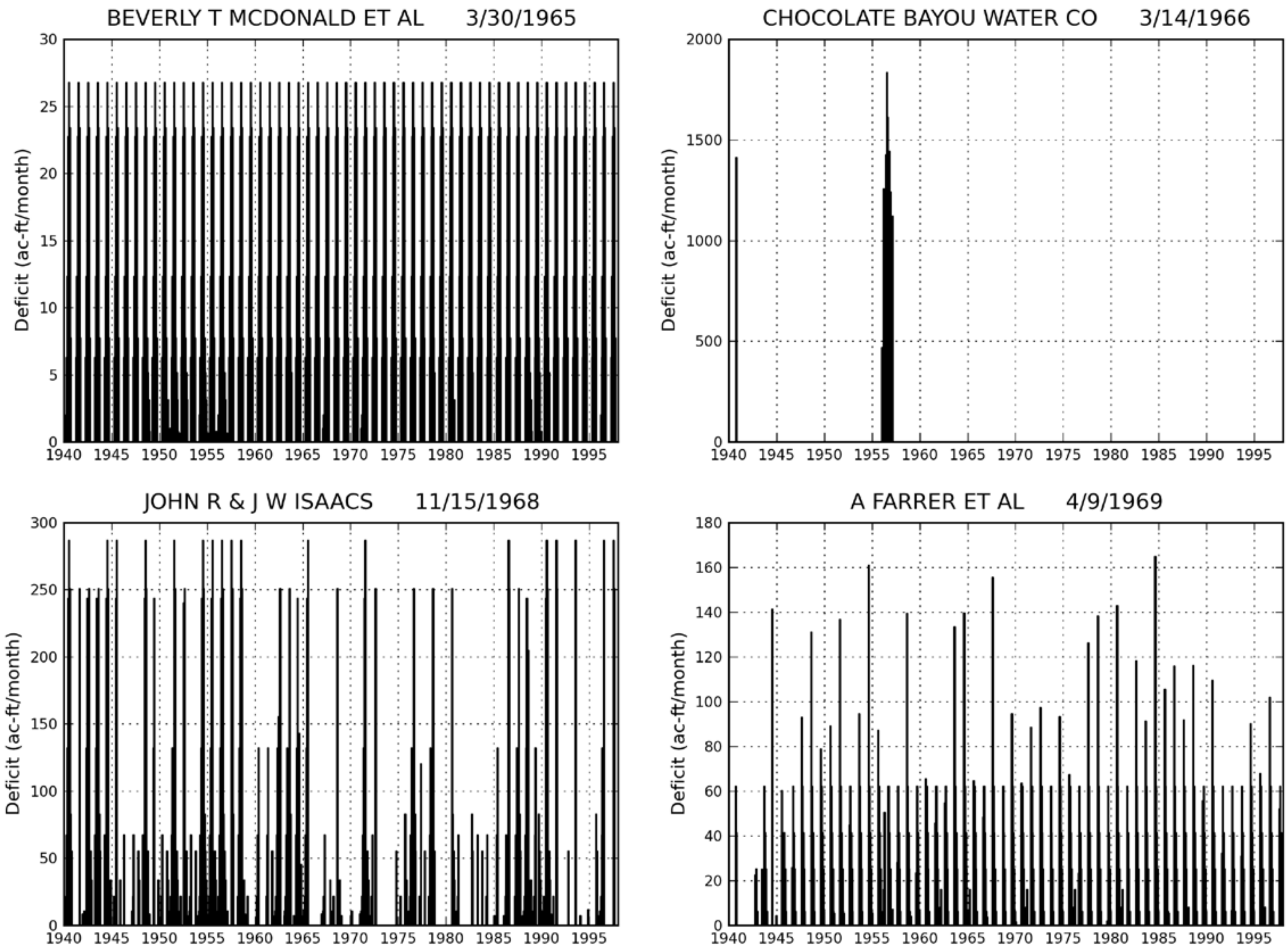

DOW CHEMICAL CO 4/3/1951
Deficit (ac-ft/month)
0
100
200
300
400
500
600
700
800
900
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

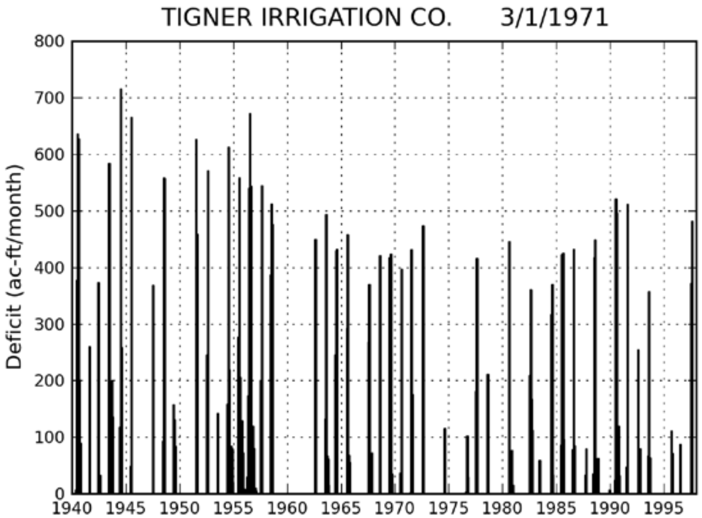

R T MARSHALL TRUSTEE 3/31/1960
Deficit (ac-ft/month)
0
5
10
15
20
25
30
35
40
45
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

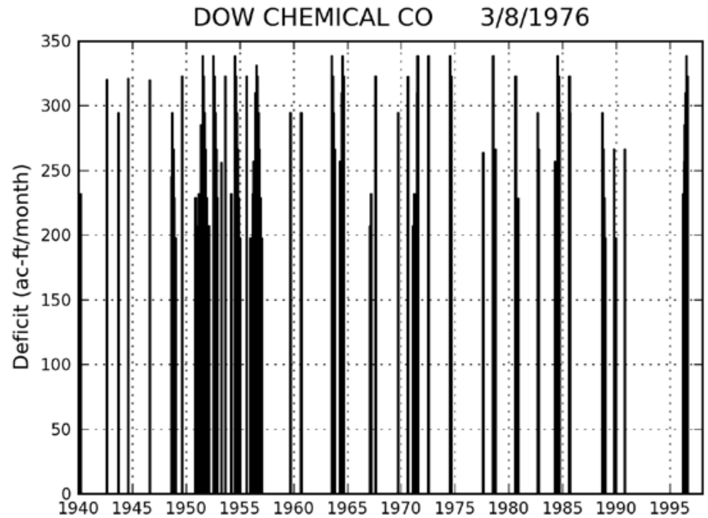

DOW CHEMICAL CO 4/4/1960
Deficit (ac-ft/month)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

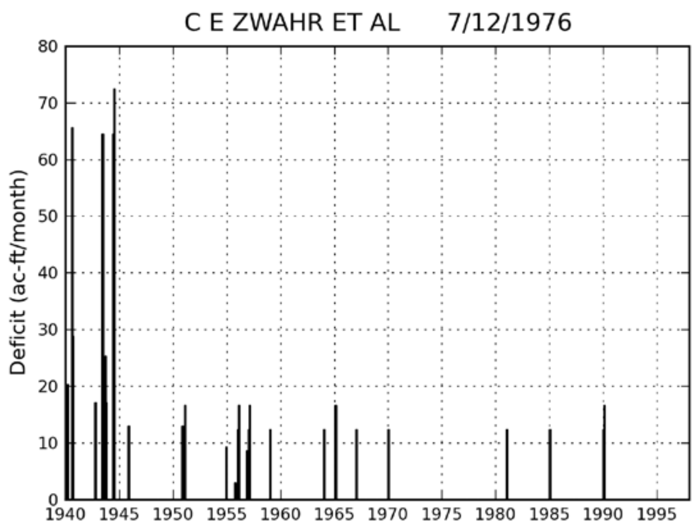

BRAZOSPORT WATER AUTHORITY 4/4/1960
Deficit (ac-ft/month)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

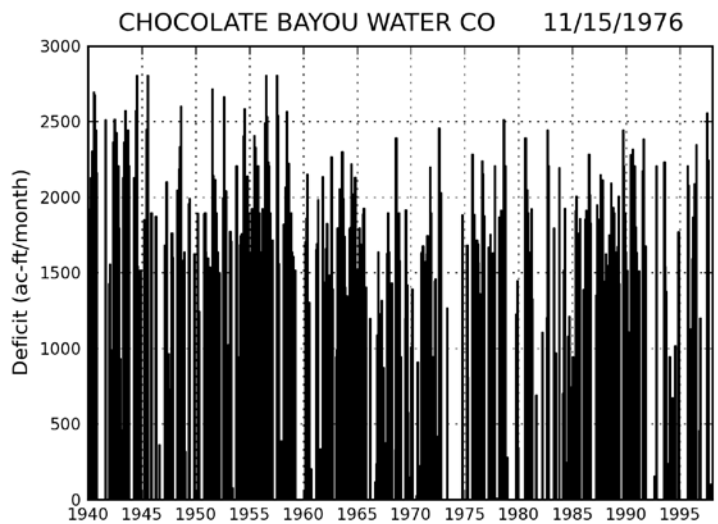

JAMES SCOPEL 4/15/1962
Deficit (ac-ft/month)
0
5
10
15
20
25
30
35
40
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

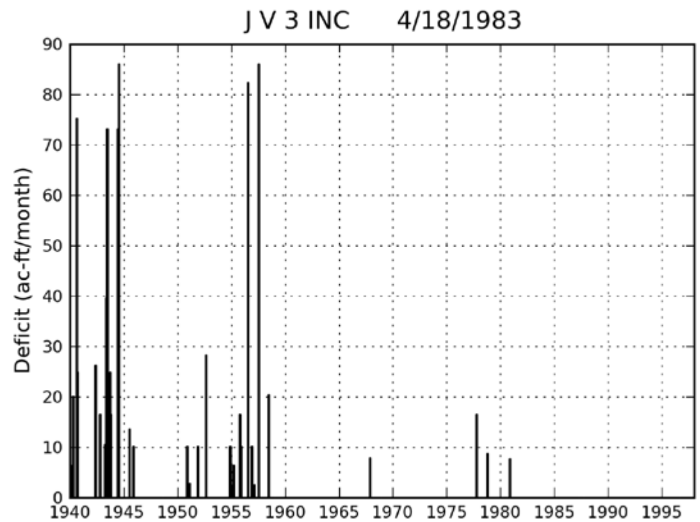

BEVERLY T MCDONALD ET AL 3/30/1965
Deficit (ac-ft/month)
0
5
10
15
20
25
30
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
CHOCOLATE BAYOU WATER CO 3/14/1966
Deficit (ac-ft/month)
0
500
1000
1500
2000
JOHN R & J W ISAACS 11/15/1968
Deficit (ac-ft/month)
0
50
100
150
200
250
300
A FARRER ET AL 4/9/1969
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
160
180

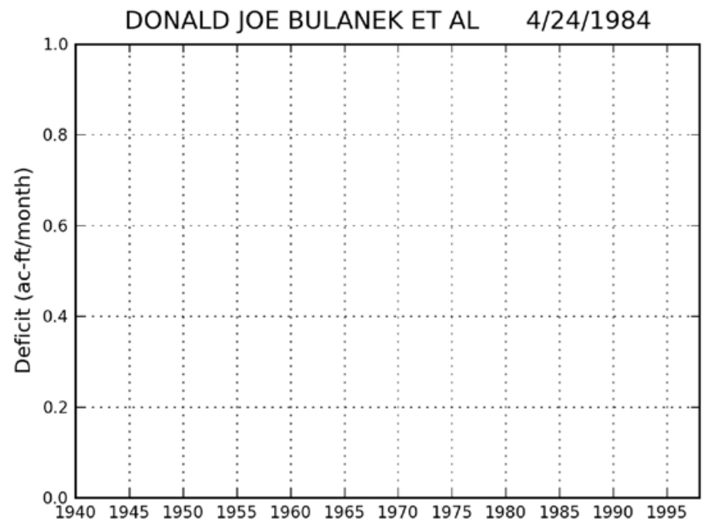

TIGNER IRRIGATION CO. 3/1/1971
Deficit (ac-ft/month)
0
100
200
300
400
500
600
700
800
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

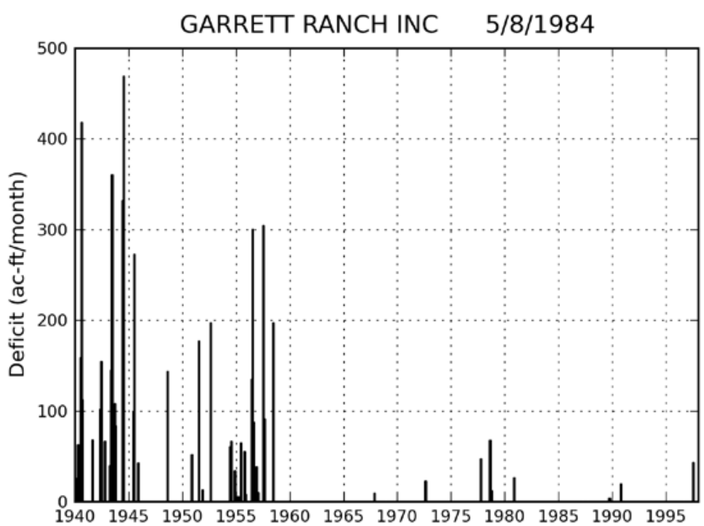

DOW CHEMICAL CO 3/8/1976
Deficit (ac-ft/month)
0
50
100
150
200
250
300
350
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

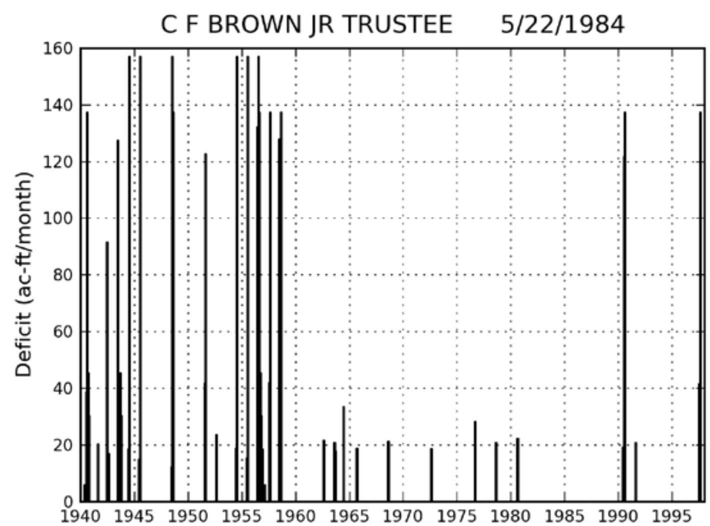

C E ZWAHR ET AL 7/12/1976
Deficit (ac-ft/month)
0
10
20
30
40
50
60
70
80
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

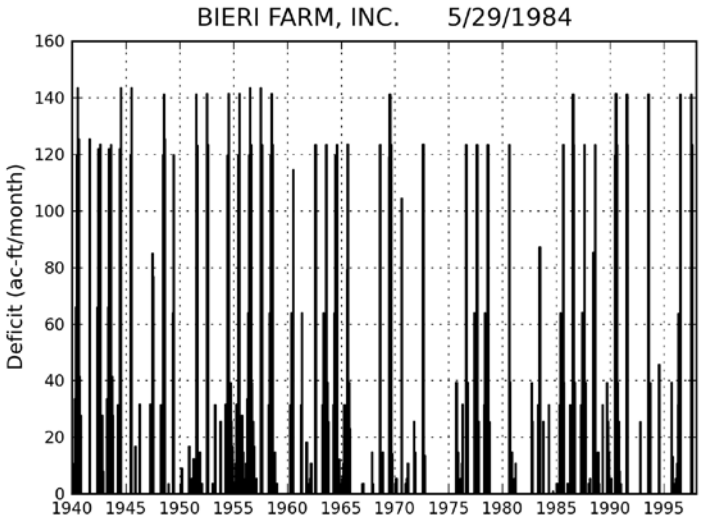

CHOCOLATE BAYOU WATER CO 11/15/1976
Deficit (ac-ft/month)
0
500
1000
1500
2000
2500
3000
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

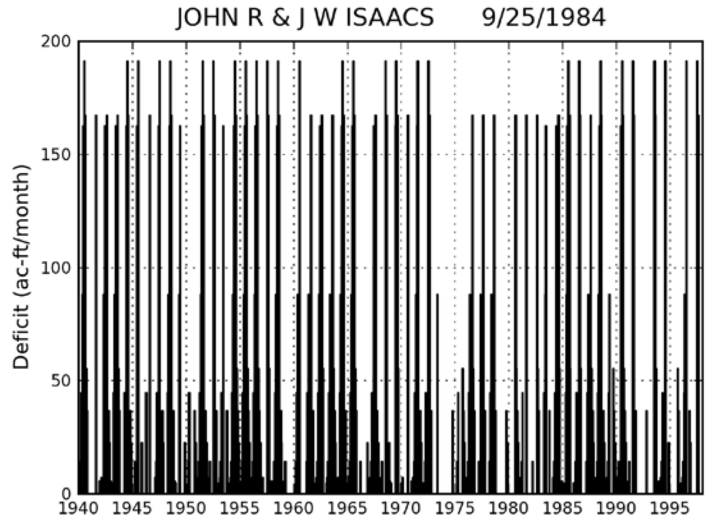

J V 3 INC 4/18/1983
Deficit (ac-ft/month)
0
10
20
30
40
50
60
70
80
90
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

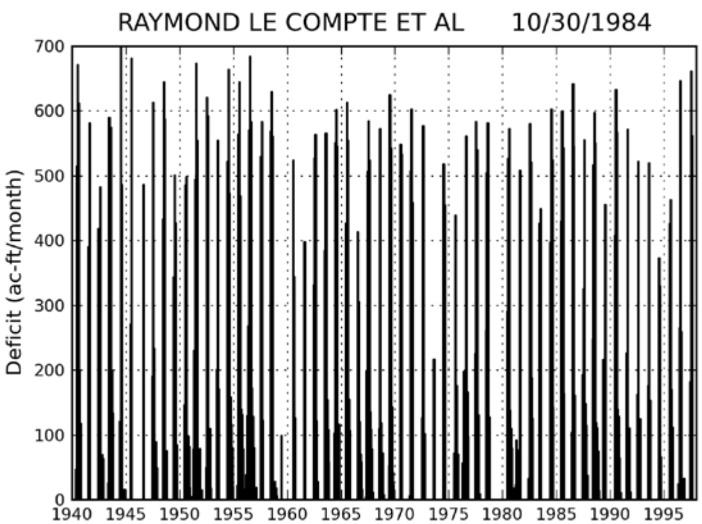

DONALD JOE BULANEK ET AL 4/24/1984
Deficit (ac-ft/month)
0.0
0.2
0.4
0.6
0.8
1.0
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

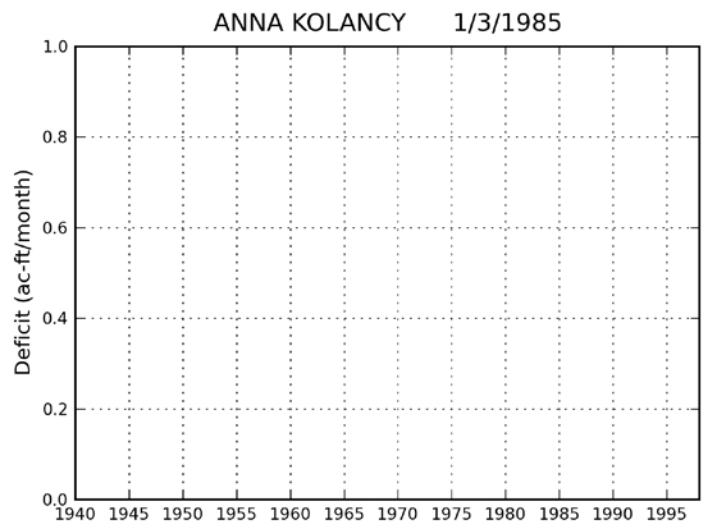

GARRETT RANCH INC 5/8/1984
Deficit (ac-ft/month)
0
100
200
300
400
500
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

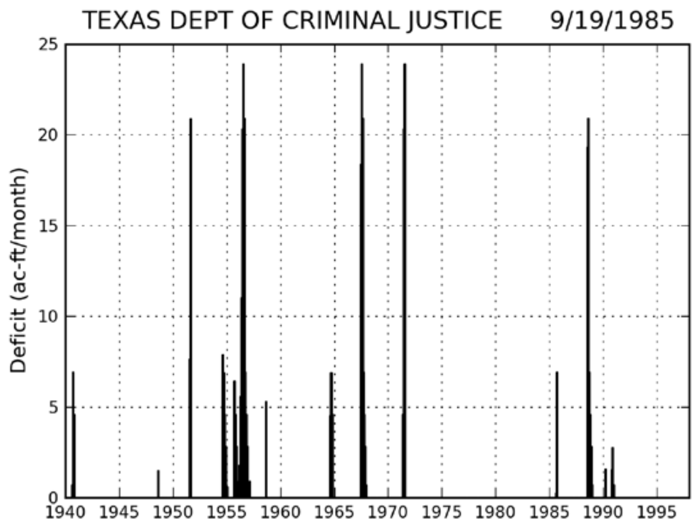

C F BROWN JR TRUSTEE 5/22/1984
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
160
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

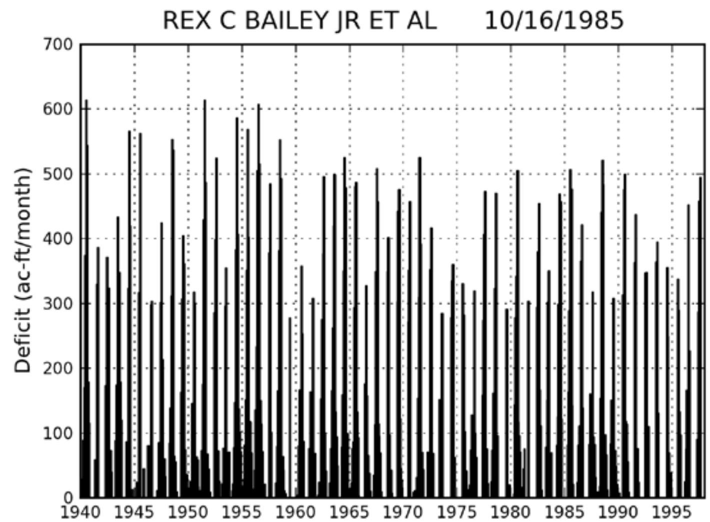

BIERI FARM, INC.   5/29/1984
Deficit (ac-ft/month)
0
20
40
60
80
100
120
140
160
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

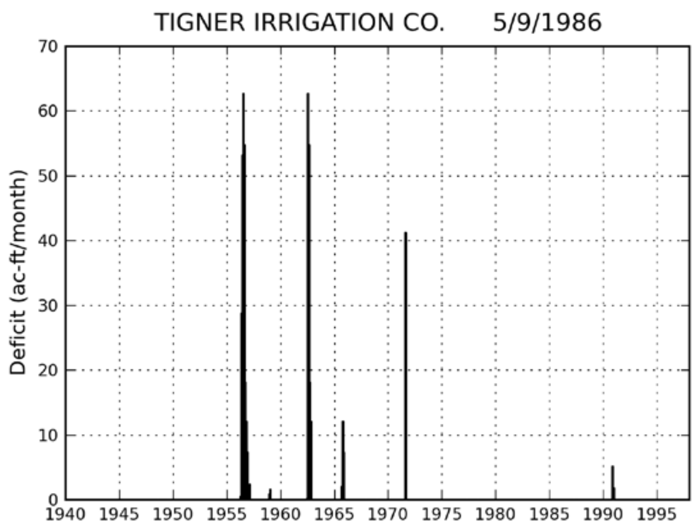

JOHN R & J W ISAACS   9/25/1984
Deficit (ac-ft/month)
0
50
100
150
200
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

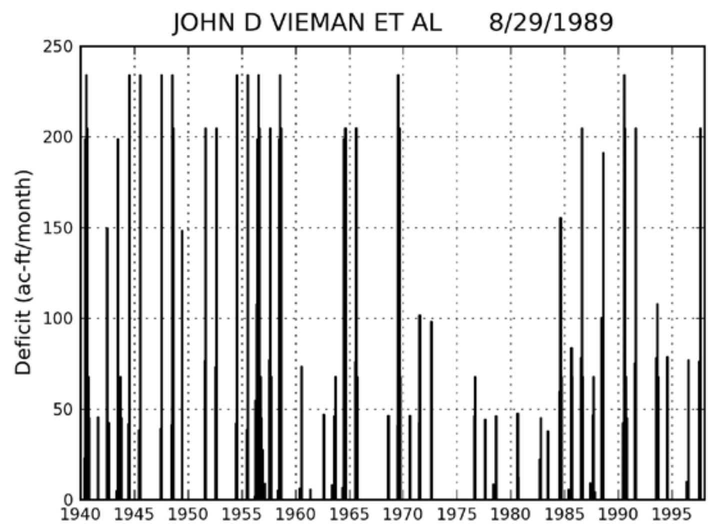

RAYMOND LE COMPTE ET AL   10/30/1984
Deficit (ac-ft/month)
0
100
200
300
400
500
600
700
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

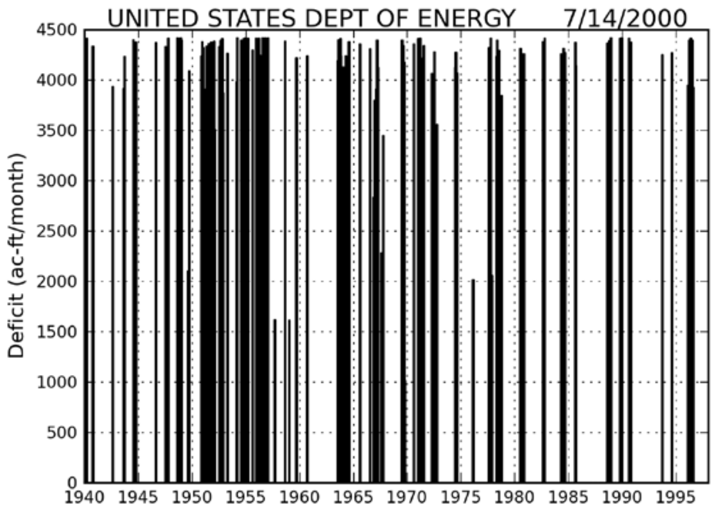

ANNA KOLANCY   1/3/1985
Deficit (ac-ft/month)
0.0
0.2
0.4
0.6
0.8
1.0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995


TEXAS DEPT OF CRIMINAL JUSTICE 9/19/1985
Deficit (ac-ft/month)
0
5
10
15
20
25
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995


REX C BAILEY JR ET AL 10/16/1985
Deficit (ac-ft/month)
0
100
200
300
400
500
600
700
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995


TIGNER IRRIGATION CO. 5/9/1986
Deficit (ac-ft/month)
0
10
20
30
40
50
60
70
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995


JOHN D VIEMAN ET AL 8/29/1989
Deficit (ac-ft/month)
0
50
100
150
200
250
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995


UNITED STATES DEPT OF ENERGY 7/14/2000
Deficit (ac-ft/month)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995