Naturalized Flow Estimates for the Brazos River Basin and the San Jacinto-Brazos Coastal Basin

Prepared for:

Texas Natural Resource Conservation Commission

TNRCC Contract Number 582-0-82108

Prepared by

Freese and Nichols, Inc.
HDR Engineering, Inc.
Crespo Consulting Services, Inc.
Densmore and DuFrain Consulting

October 2001

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Introduction

This report presents estimates of naturalized flows in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin. The estimates of naturalized flows are based on historical hydrologic records, adjusted to remove the impact of human activities. Naturalized flows were estimated at the primary control points listed in Table 1-1. All but five primary control points are at U.S. Geological Survey streamflow gages, for which historical streamflow data are available [(1)]. Two of the primary control points that are not stream gages are at reservoirs: Buffalo Springs Lake near Lubbock and Lake Graham near Graham. The remaining three control points represent locations at which water enters the Gulf of Mexico or Galveston Bay. Figure 1-1 shows the locations of the primary control points. There are 73 primary control points in the Brazos River Basin and four primary control points in the San Jacinto-Brazos Coastal Basin.

When flow records are available, estimates of naturalized flow are based on historical flow data adjusted to account for upstream diversions, return flows, changes in reservoir content, and evaporative losses from reservoirs. Streamflow loss factors are included in the adjustments for upstream activities. The procedures for flow naturalization are described below and in detail in *Appendix D of the Project Management - Detailed Workplan for Developing Naturalized Streamflows in the Brazos River and San Jacinto-Brazos River Basins* [(2)].

For many primary control points, records of historical streamflow are not available for parts of the period covered by the study, which is 1940 through 1997. When historical streamflow are not available, estimates of naturalized flow are based on relationships with other primary control points that have flow data covering the period in question. The relationships used to fill periods of missing data are described in Section 3.

Appendices B and C give the naturalized flow data for the Brazos River and San Jacinto-Brazos Coastal Basins. Other appendices gives additional information on the development of naturalized flow data and show comparisons with previous studies. Appendix P is a CD-ROM giving the naturalized flow data and the information used to develop those data.

[(1)] Superscripted numbers in parentheses match references listed in Appendix A.

Table 1-1. Primary Control Points for the Brazos River and San Jacinto-Brazos Coastal Basins

No.	ID	Name	Contributing Drainage Area (Sq. Mi.)	Incremental Drainage Area (Sq. Mi.)	Period with Data Available
B-1	RW_PL	Running Water Draw at Plainview	382	382	1/39-9/53; 10/56-4/60; 3/61-9/78
B-2	WR_SP	White River Reservoir near Spur	689	307	4/64-9/76
B-3	DU_GI	Duck Creek near Girard	279	279	10/64-9/89
B-4	SF_PE	Salt Fork Brazos River near Peacock	1,985	1,017	1/50-9/51; 10/64-9/86
B-5	CR_JA	Croton Creek near Jayton	290	290	9/59-9/86
B-6	SF_AS	Salt Fork Brazos River near Aspermont	2,496	221	6/39-1997
B-7	BS_LU	Buffalo Springs Lake near Lubbock	236	236	9/59-1997
B-8	DM_JU	Double Mountain Fork Brazos River at Justiceburg	244	244	12/61-1997
B-9	DM_AS	Double Mountain Fork Brazos River near Aspermont	1,864	1,384	6/39-1997
B-10	NC_KN	North Croton Creek near Knox City	251	251	10/65-9/86
B-11	BR_SE	Brazos River at Seymour	5,972	1,361	12/23-1997
B-12	MS_MN	Millers Creek near Munday	104	104	7/63-1997
B-13	CF_RO	Clear Fork Brazos River near Roby	228	228	1/62-1997
B-14	CF_HA	Clear Fork Brazos River at Hawley	1,416	1,188	10/67-9/89
B-15	MU_HA	Mulberry Creek near Hawley	205	205	10/67-9/89
B-16	CF_NU	Clear Fork Brazos River at Nugent	2,199	578	2/24-1997
B-17	CA_ST	California Creek near Stamford	478	478	10/62-1997
B-18	CF_FG	Clear Fork Brazos River at Fort Griffin	3,988	1,311	12/23-1997
B-19	HC_AL	Hubbard Creek below Albany	613	613	10/66-1997
B-20	BS_BR	Big Sandy Creek above Breckenridge	280	280	3/63-1997
B-21	HC_BR	Hubbard Creek near Breckenridge	1,089	196	5/55-1997
B-22	CF_EL	Clear Fork Brazos River at Eliasville	5,697	620	7/28-9/51; 10/61-9/82
B-23	BR_SB	Brazos River near South Bend	13,107	1,438	9/38-1997
B-24	GH_GH	Lake Graham near Graham	221	221	1/40-4/62; 10/63-5/70; 9/71-4/73; 8/74-7/77; 3/79-7/82; 10/84-6/89; 1/90-1997

Table 1-1, continued

No.	ID	Name	Contributing Drainage Area (Sq. Mi.)	Incremental Drainage Area (Sq. Mi.)	Period with Data Available
B-25	CC_IV	Big Cedar Creek near Ivan	97	97	12/64-9/89
B-26	SH_GR	Brazos River at Morris Sheppard Dam near Graford	14,030	605	10/76-1997
B-27	BR_PP	Brazos River near Palo Pinto	14,245	215	2/24-1997
B-28	PP_SA	Palo Pinto Creek near Santo	573	573	5/51-9/76
B-29	BR_DE	Brazos River near Dennis	15,671	853	5/68-1997
B-30	BR_GR	Brazos River near Glen Rose	16,252	581	10/23-1997
B-31	PA_GR	Paluxy River at Glen Rose	410	410	6/47-1997
B-32	NR_BL	Nolan River at Blum	282	282	12/47-2/87; 10/92-9/96; 10/97-1997
B-33	BR_AQ	Brazos River near Aquilla	17,678	734	10/38-1997
B-34	AQ_AQ	Aquilla Creek near Aquilla	308	308	1/39-1997
B-35	NB_HI	North Bosque River at Hico	359	359	1/62-1997
B-36	NB_CL	North Bosque River near Clifton	968	609	10/23-1997
B-37	NB_VM	North Bosque River At Valley Mills	1,146	178	8/59-1997
B-38	MB_MG	Middle Bosque River near McGregor	182	182	9/59-9/85; Partial 10/85-1997
B-39	HG_CR	Hog Creek near Crawford	78	78	9/59-9/85; Partial 10/85-1997
B-40	BO_WA	Bosque River near Waco	1,656	250	10/59-9/81; 4/82-6/82
B-41	BR_WA	Brazos River at Waco	20,007	365	10/14-1997
B-42	BR_HB	Brazos River near Highbank	20,870	863	10/65-1997
B-43	LE_DL	Leon River near De Leon	479	479	9/60-9/86
B-44	SA_DL	Sabana River near De Leon	264	264	9/60-9/86
B-45	LE_HS	Leon River near Hasse	1,261	524	1/39-9/91
B-46	LE_HM	Leon River near Hamilton	1,891	624	9/60-1997
B-47	LE_GT	Leon River at Gatesville	2,342	451	10/50-1997
B-48	CO_PI	Cowhouse Creek at Pidcoke	455	455	10/50-1997
B-49	LE_BE	Leon River near Belton	3,542	745	10/23-1997
B-50	LA_KE	Lampasas River near Kempner	818	818	10/62-1997
B-51	LA_YO	Lampasas River at Youngsport	1,240	422	3/24-9/80
B-52	LA_BE	Lampasas River near Belton	1,321	81	2/63-10/89; 4/99-1997
B-53	LR_LR	Little River near Little River	5,228	365	8/62-1997

Table 1-1, continued

No.	ID	Name	Contributing Drainage Area (Sq. Mi.)	Incremental Drainage Area (Sq. Mi.)	Period with Data Available
B-54	NG_GE	North Fork San Gabriel River near Georgetown	248	248	7/68-1997
B-55	SG_GE	South Fork San Gabriel River at Georgetown	133	133	12/67-1997
B-56	GA_GE	San Gabriel River at Georgetown	405	24	8/34-9/73; 11/84; 6/85-9/85; 1/86; 4/86; 7/86-8/86
B-57	GA_LA	San Gabriel River at Laneport	738	333	10/65-1997
B-58	LR_CA	Little River at Cameron	7,065	1,099	11/16-1997
B-59	BR_BR	Brazos River near Bryan	29,949	2,014	7/26-9/93
B-60	MY_DB	Middle Yegua Creek near Dime Box	236	236	8/62-1997
B-61	EY_DB	East Yegua Creek near Dime Box	244	244	8/62-1997
B-62	YC_SO	Yegua Creek near Somerville	1,009	529	6/24-8/91
B-63	DC_LY	Davidson Creek near Lyons	195	195	10/62-1997
B-64	NA_GR	Navasota River above Groesbeck	240	240	6/78-1997
B-65	BG_FR	Big Creek near Freestone	97	97	7/78-1997
B-66	NA_EA	Navasota River near Easterly	968	631	3/24-1997
B-67	NA_BR	Navasota River near Bryan	1,454	486	1/51-9/94
B-68	BR_HE	Brazos River near Hempstead	34,314	1,707	10/38-1997
B-69	MC_BL	Mill Creek near Bellville	376	376	8/63-9/92
B-70	BR_RI	Brazos River at Richmond	35,441	751	10/22-1997
B-71	BG_NE	Big Creek near Needville	43	43	6/47-6/50; 4/52-1997
B-72	BR_RO	Brazos River at Rosharon	35,773	289	4/67-9/80; 5/84-1997
B-73	BR_GM	Brazos River at Gulf of Mexico	35,931	158	None
BSJ-1	CL_PE	Clear Creek near Pearland	39	39	8/44-10/44; 3/46-10/46; 4/47-12/59; 4/63-9/92
BSJ-2	CB_AL	Chocolate Bayou near Alvin	88	88	8/44; 4/46; 1/47-1/58; 3/59-1997
BSJ-3	SJ_GB	San Jacinto-Brazos Coastal Basin at Galveston Bay	1,145	1,019	None
BSJ-4	SJ_GM	San Jacinto-Brazos Coastal Basin at the Gulf of Mexico	293	293	None

1.1 Specific Techniques for Naturalization of Flows in the Brazos River Basin

Naturalization of Flow Data

Naturalized flow data are based on historical flows, adjusted to remove the effects of human activity. A general equation for naturalized flow is as follows:

Naturalized Flow = Historical Flow + Delivery Factor * (Upstream Diversions – Upstream Return Flows + Changes in Upstream Reservoir Contents + Upstream Reservoir Evaporation)

The elements of the equation are determined as follows:

Historical Flow – Flow recorded at USGS streamflow gages or estimated from reservoir spills and releases.

Upstream Diversions – Upstream diversions as recorded in TNRCC records, Brazos River Authority and other water right holder records, or as estimated when records are missing.

Upstream Return Flows – Upstream return flows as recorded in TNRCC records or as estimated when records are missing. Table L-1 lists significant wastewater discharges in the Brazos River Basin used in the naturalization process. Table L-2 lists significant wastewater discharges in the San Jacinto-Brazos Coastal Basin. Generally, all wastewater discharges as provided by TNRCC were included in the naturalization. However, when data were missing estimates of historical discharges were not made for permits of less than 1 MGD.

Changes in Upstream Reservoir Contents – Changes in content for major upstream reservoirs are based on USGS records, Texas Water Development Board records and records kept by others, or estimates of content changes if records are not available. Table L-3 summarizes the method used for estimating content change for each major reservoir. Content changes for reservoirs with less than 5,000 acre-feet of permitted conservation storage were not used. (Lake Mexia, which has less than 5,000 acre-feet of conservation storage, is permitted for 9,600 acre-feet of storage.) In general data are not available for smaller reservoirs and the impact of content change in these reservoirs on streamflows is minimal.

Upstream Reservoir Evaporation – Evaporation from upstream reservoirs, estimated by multiplying the net reservoir evaporation rate by the reservoir surface area. Table L-3 summarizes the method for estimating the reservoir surface area for each major reservoir. Evaporation from reservoirs with less than 5,000 acre-feet of permitted conservation storage was not used in the calculations. The impact of evaporation from these smaller reservoirs on streamflows is minimal.

Delivery Factor - (1 - channel loss factor)- applied to changes in flow. This factor is used to account for changes in the amount of water lost between control points from losses under natural conditions. Further discussion on reservoir loss factors may be found in Section 2 and Appendix D.

Many reservoirs in the Brazos River Basin make large releases for downstream use, transporting the water by the bed and banks of natural streams. In some cases these releases will pass and be measured by downstream gages before being diverted from the stream. The releases should not be treated as diversions in the computation of naturalized flows for the primary control points between the reservoir and the point of use.

Computation of Adjusted Net Reservoir Evaporation Rates

Adjusted net reservoir evaporation is the rate at which water is lost to evaporation from the surface of a reservoir. It represents the net impact of evaporation and of rainfall directly on the reservoir surface. The equation for adjusted net reservoir evaporation is as follows:

Adjusted Net Reservoir Evaporation = Gross Reservoir Evaporation – Rainfall + the Portion of Rainfall That Would Have Run Off in the Absence of a Reservoir.

The sources of the data needed to determine reservoir evaporation rates are as follows:

Gross Reservoir Evaporation – Gross evaporation rates have been measured for some of the study period at several of the large reservoirs, as shown in Table L-4. When pan measurements at the reservoir are available they were used to estimate reservoir evaporation. For those reservoirs where these data are unavailable, or for periods when pan evaporation is unavailable, evaporation rates were derived using TWDB quadrangle data. Monthly values for a specific location are derived by taking a weighted average for up to 4 nearby quadrangles. Table L-5 summarizes the quadrangle factors that were used to estimate gross reservoir evaporation when pan measurements are missing or not available.

Precipitation – Precipitation records are available throughout the basin from the National Oceanic and Atmospheric Administration and TWDB. Precipitation data by quadrangle are available from the TWDB for 1940 through 1997 [(8)]. As with pan evaporation, local rainfall data recorded at a reservoir site were used where available. When necessary, the TWDB quadrangle data were used to estimate precipitation.

The Portion of Rainfall That Would Have Run Off in the Absence of a Reservoir – Runoff (expressed as inches) is generally obtained from a nearby USGS gage or gages. Table L-6 shows streamflow gages that were used to estimate quadrangle runoff for each quadrangle.

Area and Capacity

Appendix M contains tables showing the original area and capacity characteristics for each major reservoir in the study area and similar tables that are the results of sediment surveys made since the reservoirs began operation [(20-36)].

For this study, seven of eight runs specified in the scope include original area and capacity conditions. The remaining run includes estimated year 2000 area and capacity conditions. The year 2000 area and capacity conditions were estimated using available information from recent TWDB sediment surveys as well as historical sedimentation reports [16,17].

1.2 Specific Techniques for Determining Naturalized Flows for the San Jacinto-Brazos Coastal Basin

There are three USGS streamflow gages in the San Jacinto-Brazos Coastal Basin with long periods of record. However, flow in these streams is heavily affected by manmade influences, including large irrigation diversions upstream and large releases of water from upstream reservoirs for industrial use downstream. Naturalized flows were estimated at the Clear Creek near Pearland and Chocolate Bayou near Alvin USGS gages in the San Jacinto-Brazos Coastal Basin using available data. The calculated naturalized flows were compared to flows derived from a rainfall-runoff model developed by the TWDB (see Appendix N). Outside of the historical period for these two gages, the naturalized flows were derived from the TWDB rainfall-runoff model.

1.3 Data Sources and Methods of Filling Missing Data

The estimates of naturalized flow are based on historical streamflow data as recorded by U.S. Geological Survey streamflow gages. To convert historical flows to naturalized flows, gaged flows are adjusted by adding historical diversions, subtracting historical return flows, adding historical changes in upstream reservoir contents, and adding historical net evaporation losses from upstream reservoirs. These upstream changes were adjusted for channel losses as described in Section 4 below.

Historical Diversions

Historical diversions are based on self-reported data from water right holders maintained by the Texas Natural Resource Conservation Commission (TNRCC) [4]. Data in the TNRCC electronic database were compared with TNRCC files and corrected where appropriate. Since historical diversions are added to historical streamflows in the naturalization process, the assumption of no diversion results in a conservatively low estimate of naturalized flows. For that reason, historical diversions were seldom estimated when records were missing. Diversions were only estimated for rights with a clear record of consistent diversions and a few years of missing information. In some cases, recorded diversions that greatly exceeded water rights were assumed to be incorrect data and were not used in naturalization. The specific adjustments to recorded diversions are discussed in the water use files included in the CD-ROM, Appendix P.

There are some water rights in the Brazos River Basin that are released from reservoirs and diverted downstream. In the naturalization process, it is the location of the diversion from the stream that matters, and this is not generally reflected in TNRCC records. All municipal use from Lake Palo Pinto was assumed to be diverted from Palo Pinto Creek downstream of the PP_SA control point. The amount released from Brazos River Authority (BRA) reservoirs for downstream diversion, the amount diverted directly from BRA reservoirs, and the location of the downstream diversions were developed on the basis of information provided by the BRA [5] and information in Freese and Nichols' files [6]. The amount diverted was based on the best available information, which included records provided by downstream users, TNRCC contract diversion records, and estimates based on BRA releases less channel losses. The water use files included in the CD-ROM, Appendix P, show the basis for the diversions used.

Return Flows

Data on return flows of treated wastewater since the mid-1970s are available from the Texas Natural Resource Conservation Commission. Return flow data from earlier years are extremely limited. Even for the period with records available, some months are missing and some records appear to be inconsistent. Missing return flow data were estimated on the basis of use in other years and changes in population. Estimates for the early years of the study (1940 through mid-1970's) are less reliable than the actual data available in recent years. Return flow data for stormwater discharges or once-through cooling water discharges were not included in the naturalization process, since they do not reflect artificial increases to natural flows. Reported consumptive use from industrial recirculations is accounted for in the historical diversions.

In some cases, diversions from one part of the Brazos River Basin are released into the stream elsewhere. If the diversion and the release are in the same primary control point watershed, no adjustment is needed. However, if water is diverted in one primary control point watershed and released in another, the release should appear as a return flow in the receiving watershed. Examples of this operation include Alcoa's diversions from the Little River released into East Yegua Creek and Reliant Energy's (formerly Houston Lighting and Power's) diversion from the Brazos River released into Smithers Lake on Dry Creek.

Generally, irrigation diversions are assumed to have no return flow. Irrigation return flows in the lower Brazos River Basin are discharged outside of the basin, primarily into the San-Jacinto-Brazos Coastal Basin. Irrigation return flows above the Chocolate Bayou near Alvin gage, which is in the San-Jacinto Brazos Coastal Basin, are included in the naturalization calculations.

Changes in Reservoir Content

Figure 1-2 shows the locations of reservoirs in the Brazos River Basin that were included in the naturalization process. The most reliable data on changes in reservoir content are U.S. Geological Survey reservoir content data, which are available for most of the major reservoirs in the Brazos River Basin. If U.S. Geological Survey data were not available, data were obtained from reservoir owners (if possible) or from data provided by the Texas Water Development Board. If no data were available, changes in reservoir contents were estimated on the basis of reservoir operation studies. The reservoir operation study is an iterative water balance spreadsheet model that uses runoff, demand, and net evaporation rate to determine the end of month content, average area, evaporation and spills. Table L-3 gives specific information regarding the source of content change data.

Net Evaporation Losses from Reservoirs

Historical net evaporation losses from reservoirs were determined by multiplying the historical reservoir surface area by the net reservoir evaporation rate. Surface areas were based on reservoir contents and area-capacity-elevation relationships for the reservoirs. The net reservoir evaporation rates for reservoirs were based on data from nearby evaporation and rainfall gages where available [(7)]. For reservoirs without nearby evaporation gages, Texas Water Development Board data on reservoir evaporation rates were used [(8,9)]. Table 1-2 list the reservoirs used in the naturalization process.

Table 1-2. Major Reservoirs in the Brazos River Basin

Reservoir	Contributing Drainage Area (Square Miles)	Conservation Storage (Ac-Ft)			WR No.
		Permitted	Original	Surveyed	
White River	689 [a]	44,897	44,910	31,843	CA-3693
Buffalo Springs	236	4,730	4,200 [d]		CA-3706
Alan Henry	395	115,937			P-4146
Davis		4,477	5,400		CA-3440
Sweetwater	104	10,000	11,900 [c]		CA-4130
Abilene	110	11,868	7,900	6,680	CA-4142
Kirby	44	8,500	7,620 [b]	7,620	CA-4150 A
Fort Phantom Hill	470	73,960	74,310	70,036	CA-4151
Stamford	360	59,810	57,630	51,054	CA-4179 A
Cisco	26	45,000	26,000		CA-4211A
Hubbard	1,085	317,750	314,280	324,983	CA-4213 B
Daniel	115	11,400	9,515	6,115	CA-4214
Millers Creek	228	30,696	25,520	27,888	CA-3444
Graham	221	52,389 [e]	53,680	52,750	CA-3458
Possum Kingdom	14,030	724,739	724,700	570,243	CA-5155
Palo Pinto	471	44,100 [f]	44,100		CA-4031
Mineral Wells	63	8,140 [g]	6,760		CA-4039
Squaw Creek	64	151,500	151,500		CA-4097
Granbury	16,113	155,000	153,500	136,823	CA-5156
Pat Cleburne	100	25,600	25,560	25,250	CA-4106
Whitney	17,623	50,000	642,179	627,100	CA-5157
Aquilla	252	52,400	52,400	45,937	CA-5158
Waco	1,652	104,100	152,500	144,830	P-5094
Tradinghouse	39	37,814	37,814	37,800	CA-4342
Lake Creek	17	8,500	8,400		CA-4345
Marlin City Lake	18	6,847			CA-4355 A
Leon	252	28,000	27,290	26,940	CA-3470 B
Proctor	1,259	59,400	59,400	55,715	CA-5159

Table 1-2, continued

Reservoir	Contributing Drainage Area (Square Miles)	Conservation Storage (Ac-Ft)			WR No.
		Permitted	Original	Surveyed	
Belton	3,531	457,600	457,600	434,500	CA-5160, CA-2936 A
Stillhouse Hollow	1,313	235,700	235,700	225,909	CA-5161
Georgetown	247	37,100	37,100	37,010	CA-5162
Granger	709	65,500	65,500	54,280	CA-5163
Alcoa	6	14,750	14,750	14,600	CA-5272
Sandow Surface Lignite Mine		7,529			CA-5540
Somerville	1,007	160,110	160,100	155,062	CA-5164
Mexia	198	9,600	10,000	4,806	CA-5287
Limestone	675	225,400	225,400	215,751	CA-5165
Twin Oaks	45	30,319	30,300		CA-5298
Camp Creek	40	8,400	8,550	8,350	CA-5301
Gibbons Creek	16	32,084	26,800		CA-5311 A
Smithers	24	18,750	18,700	18,680	CA-5325

Notes
a Design engineers report 172 square mile contributing drainage area. 689 sq. mi. is reported by USGS.
b Capacity in 1941 US SCS survey
c Capacity in 1948 Water Supply Report by Freese and Nichols
d Capacity in 1957
e Combined permitted capacity of Lake Eddleman and Lake Graham when they combined in 1959
f Lake Palo Pinto enlarged from 34,250 acre-feet in 11/65
g Lake Mineral Wells enlarged from 7300 acre-feet in 1943

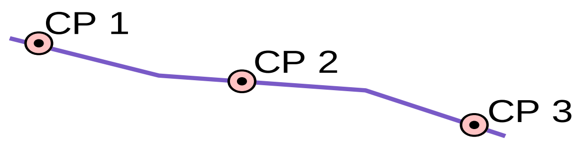
1.4 Adjustment for Negative Naturalized Flows

It is possible to compute negative monthly values for naturalized flows in the streamflow naturalization process. There are several potential causes of these negative values:

- Incorrect data on historical streamflows or upstream adjustments (streamflows too low, return flows too high, diversions too low, change in reservoir contents too low, evaporation too low, etc.)
- Losses different from those assumed in the naturalization process
- Timing problems, in which the effect of an upstream change arrives at the control point in a different month.

Most of the negative flows are relatively small, with larger values sometimes occurring downstream from major reservoirs. In this study, months with negative naturalized flows were reviewed carefully to correct any data problems that could be found. Corrections to data included revisions made to electronic TNRCC diversions based on review of the TNRCC paper water use records and adjusting abnormally high or low values. Remaining negative naturalized flows were set to zero. The following example describes this process.

The following equations using the figure below describe how adjustments are passed to the downstream control point.



The adjustments to the upstream control point (CP2) are computed.

Adjustment CP2 = Diversions CP2 – Return Flows CP2 + Evaporative Losses CP2 + Change in Storage CP2 + Delivery Factor * (Diversions CP1 – Return Flows CP1 + Evaporative Losses CP1 + Change in Storage CP1)

A negative naturalized flow at the upstream control point (CP2) occurs when the adjustments are a negative number with an absolute value greater than the historical flow at the control point. If the adjustments are greater than the historical flow, the adjustments are changed to equal the negative of the historical flow, resulting in zero naturalized flow.

If Adjustment CP2 < (- Historical Flow CP2), then Adjustment CP2 = (- Historical Flow CP2)
Natural Flow CP2 = Historical Flow CP2 + Adjustment CP2

The adjustments are passed to the downstream control point.

Adjustment CP3 = Diversions CP3 – Return Flows CP3 + Evaporative Losses CP3 + Change in Storage CP3 + Delivery Factor * Adjustment CP2

1.5 Eliminated Control Point

The Oyster Creek near Alvin, a primary control point listed in the Workplan [2] in the San Jacinto-Brazos Coastal Basin, was eliminated during the development of naturalized flow data. Notes in the U.S. Geological Survey streamflow records for the Oyster Creek near Alvin gage indicated that a large portion of the flow in the creek results from releases by Dow Chemical. Records for releases above this control point were not available for seventeen of the thirty-six years that this gage was in operation. Records of releases published by the USGS in the remaining nineteen years could not be verified by Dow Chemical. In the upper portion of the Oyster Creek watershed most of the flow in the stream is actually water being delivered from the Brazos River to the Canal A system using the bed and banks of Jones Creek and Oyster Creek. An unknown portion of the overflow from this canal system is added to the flows below the Canal A diversion south of Missouri City in Fort Bend County. Several water rights in Fort Bend County appear to be dependent upon Canal A flows or overflows. In addition, there appear to be at least two points where flows from Oyster Creek may re-enter the main stem of the Brazos River rather than continue downstream to the stream gage. As a result, many of the assumptions made in flow naturalization may not be valid at this control point.

1.6 Springflows and Their Effect on Naturalized Flows

The impact of groundwater development on streamflows in the Brazos River Basin has not been documented. Inspection of historical records does not show any marked changes in flow that may be attributed to changes in springflow. Therefore, no adjustments of gaged or naturalized flows were made to remove or adjust for the effects of groundwater development in the Brazos River and San Jacinto-Brazos Coastal Basins.

Channel Losses

Appendix D includes a discussion of the methodology used to determine channel losses in the Brazos River Basin for this study. Channel losses were based on information provided by the Brazos River Authority [10], previous studies of channel losses in the upper Brazos River Basin conducted by Freese and Nichols [11], previous studies of channel losses in the Bosque watershed conducted by HDR [12], and channel loss studies conducted for this project. Table 2-1 gives the delivery factor from each primary control point to the next downstream control point. The delivery factor is the fraction of upstream flows that reaches the downstream point and is equal to one minus the channel losses expressed as a fraction. Because the gaged records already reflect channel losses that occurred historically, channel losses in the flow naturalization and simulation are applied to changes in flow only, not to total flow.

The delivery factors selected for this study represent long-term averages. Loss rates during drought times have been shown to be substantially greater than those selected for this study and delivery factors, which are defined as 1.0 – loss rate, are substantially lower during droughts[38]. The gaged flows upon which the naturalized flows are based inherently include the effects of channel losses. Accordingly, during the naturalization process, the delivery factors were applied to changes in flow that were added to or subtracted from the gaged flows (effluent discharges, historical diversions, changes in storage, etc.).

Between two control points CP1 (upstream) and CP2 (downstream), the naturalized flows at the downstream point (CP2) is computed as follows:

Naturalized Flow CP2 = Historical Flow CP2 + Diversions CP2 – Return Flows CP2 + Evaporative Losses CP2 + Change in Storage CP2 + Delivery Factor Between CP1 and CP2 * (Diversions CP1 – Return Flows CP1 + Evaporative Losses CP1 + Change in Storage CP1).

Table 2-1. Control Points and Corresponding Delivery Factors

No.	ID	Name	ID of Downstream Control Point	Delivery Factor to Next Downstream Primary CP
B-1	RW_PL	Running Water Draw at Plainview	WR_SP	0.05000
B-2	WR_SP	White River Reservoir near Spur	SF_PE	0.61769
B-3	DU_GI	Duck Creek near Girard	SF_PE	0.80101
B-4	SF_PE	Salt Fork Brazos River near Peacock	SF_AS	0.84748
B-5	CR_JA	Croton Creek near Jayton	SF_AS	0.88268
B-6	SF_AS	Salt Fork Brazos River near Aspermont	BR_SE	0.53157
B-7	BS_LU	Buffalo Springs Lake near Lubbock	DM_AS	0.32574
B-8	DM_JU	Double Mountain Fork Brazos River at Justiceburg	DM_AS	0.51300

Table 2-1, continued

No.	ID	Name	ID of Downstream Control Point	Delivery Factor to Next Downstream Primary CP
B-9	DM_AS	Double Mountain Fork Brazos River near Aspermont	BR_SE	0.50862
B-10	NC_KN	North Croton Creek near Knox City	BR_SE	0.62723
B-11	BR_SE	Brazos River at Seymour	BR_SB	0.57884
B-12	MS_MN	Millers Creek near Munday	BR_SB	0.53779
B-13	CF_RO	Clear Fork Brazos River near Roby	CF_HA	0.66280
B-14	CF_HA	Clear Fork Brazos River at Hawley	CF_NU	0.88030
B-15	MU_HA	Mulberry Creek near Hawley	CF_NU	0.89757
B-16	CF_NU	Clear Fork Brazos River at Nugent	CF_FG	0.56482
B-17	CA_ST	California Creek near Stamford	CF_FG	0.67221
B-18	CF_FG	Clear Fork Brazos River at Fort Griffin	CF_EL	0.68637
B-19	HC_AL	Hubbard Creek below Albany	HC_BR	0.86321
B-20	BS_BR	Big Sandy Creek above Breckenridge	HC_BR	0.90326
B-21	HC_BR	Hubbard Creek near Breckenridge	CF_EL	0.84488
B-22	CF_EL	Clear Fork Brazos River at Eliasville	BR_SB	0.91272
B-23	BR_SB	Brazos River near South Bend	SH_GR	0.98237
B-24	GH_GH	Lake Graham near Graham	SH_GR	0.98333
B-25	CC_IV	Big Cedar Creek near Ivan	SH_GR	0.99139
B-26	SH_GR	Brazos River at Morris Sheppard Dam near Graford	BR_PP	0.99487
B-27	BR_PP	Brazos River near Palo Pinto	BR_DE	0.98032
B-28	PP_SA	Palo Pinto Creek near Santo	BR_DE	0.95937
B-29	BR_DE	Brazos River near Dennis	BR_GR	0.98000
B-30	BR_GR	Brazos River near Glen Rose	BR_AQ	0.97801
B-31	PA_GR	Paluxy River at Glen Rose	BR_AQ	0.97770
B-32	NR_BL	Nolan River at Blum	BR_AQ	0.98776
B-33	BR_AQ	Brazos River near Aquilla	BR_WA	0.98733
B-34	AQ_AQ	Aquilla Creek near Aquilla	BR_WA	0.99269
B-35	NB_HI	North Bosque River at Hico	NB_CL	0.78957
B-36	NB_CL	North Bosque River near Clifton	NB_VM	0.93648
B-37	NB_VM	North Bosque River At Valley Mills	BO_WA	0.88857
B-38	MB_MG	Middle Bosque River near McGregor	BO_WA	0.94499
B-39	HG_CR	Hog Creek near Crawford	BO_WA	0.94601
B-40	BO_WA	Bosque River near Waco	BR_WA	0.98510
B-41	BR_WA	Brazos River at Waco	BR_HB	0.98619
B-42	BR_HB	Brazos River near Highbank	BR_BR	0.98035
B-43	LE_DL	Leon River near De Leon	LE_HS	0.80254

Table 2-1, continued

No.	ID	Name	ID of Downstream Control Point	Delivery Factor to Next Downstream Primary CP
B-44	SA_DL	Sabana River near De Leon	LE_HS	0.82774
B-45	LE_HS	Leon River near Hasse	LE_HM	0.63000
B-46	LE_HM	Leon River near Hamilton	LE_GT	0.97510
B-47	LE_GT	Leon River at Gatesville	LE_BE	0.97109
B-48	CO_PI	Cowhouse Creek at Pidcoke	LE_BE	0.99275
B-49	LE_BE	Leon River near Belton	LR_LR	0.99390
B-50	LA_KE	Lampasas River near Kempner	LA_YO	0.99121
B-51	LA_YO	Lampasas River at Youngsport	LA_BE	0.99217
B-52	LA_BE	Lampasas River near Belton	LR_LR	0.99477
B-53	LR_LR	Little River near Little River	LR_CA	0.97831
B-54	NG_GE	North Fork San Gabriel River near Georgetown	GA_GE	0.99854
B-55	SG_GE	South Fork San Gabriel River at Georgetown	GA_GE	0.99887
B-56	GA_GE	San Gabriel River at Georgetown	GA_LA	0.99107
B-57	GA_LA	San Gabriel River at Laneport	LR_CA	0.98762
B-58	LR_CA	Little River at Cameron	BR_BR	0.96473
B-59	BR_BR	Brazos River near Bryan	BR_HE	0.97315
B-60	MY_DB	Middle Yegua Creek near Dime Box	YC_SO	0.97764
B-61	EY_DB	East Yegua Creek near Dime Box	YC_SO	0.98052
B-62	YC_SO	Yegua Creek near Somerville	BR_HE	0.97487
B-63	DC_LY	Davidson Creek near Lyons	BR_HE	0.97181
B-64	NA_GR	Navasota River above Groesbeck	NA_EA	0.98678
B-65	BG_FR	Big Creek near Freestone	NA_EA	0.99323
B-66	NA_EA	Navasota River near Easterly	NA_BR	0.99034
B-67	NA_BR	Navasota River near Bryan	BR_HE	0.95909
B-68	BR_HE	Brazos River near Hempstead	BR_RI	0.97049
B-69	MC_BL	Mill Creek near Bellville	BR_RI	0.98008
B-70	BR_RI	Brazos River at Richmond	BR_RO	0.98969
B-71	BG_NE	Big Creek near Needville	BR_RO	0.99036
B-72	BR_RO	Brazos River at Rosharon	BR_GM	0.98344
B-73	BR_GM	Brazos River at Gulf of Mexico	-	N/A
BSJ-1	CL_PE	Clear Creek near Pearland	SJ_GB	0.98899
BSJ-2	CB_AL	Chocolate Bayou near Alvin	SJ_GB	0.99427
BSJ-3	SJ_GB	San Jacinto-Brazos Coastal Basin at Galveston Bay	-	N/A
BSJ-4	SJ_GM	San Jacinto-Brazos Coastal Basin at the Gulf of Mexico	-	N/A

Filling Naturalized Flows

For this study, naturalized flow data were developed for January 1940 through December 1997. As can be seen in Table 1-1, streamflow data are not available to cover the entire period for many of the primary control points. To fill these missing data, statistical relationships were established with other primary control points for which data were available. Table 3-1 shows the relationships used to fill missing data. Several different potential fill relationships were tried for most control points, and Appendix E lists all of the relationships tried for each control point. For some primary control points, particularly in the upper basin, there are no close statistical relationships available to fill data. The higher the R^2 value in Table 3-1, the better the statistical relationship between gages. In general, relationships with R^2 above 0.60 are acceptable, and those with R^2 above 0.80 are good. If relationships with a high R^2 were not available, the best available relationship was used.

Table 3-1. Relationships Used to Fill Missing Data

No.	***ID***	***Name***	***Data Missing***	***Fill Relationship Used***	***R^2 for Fill Rel.***
B-1	RW_PL	Running Water Draw at Plainview	10/53-9/56; 5/60-2/61	RW_PL = 0.033 * SF_AS	0.194
			10/78-1997	RW_PL = 0.141 * WR_SP	0.442
B-2	WR_SP	White River Reservoir near Spur	1/40-8/63	WR_SP = 0.207 * SF_AS	0.391
B-3	DU_GI	Duck Creek near Girard	1/40-9/64; 10/89-1997	DU_GI = 0.138 * SF_AS	0.609
B-4	SF_PE	Salt Fork Brazos River near Peacock	1/40-12/49; 10/51-9/64; 10/86-1997	SF_PE = 0.701 * SF_AS	0.921
B-5	CR_JA	Croton Creek near Jayton	1/40-9/59; 10/86-1997	CR_JA = 0.153 * SF_AS	0.540
B-6	SF_AS	Salt Fork Brazos River near Aspermont	None	-	-
B-7	BS_LU	Buffalo Springs Lake near Lubbock	1/40-8/59	BS_LU = 0.129 * DM_AS	0.447
B-8	DM_JU	Double Mountain Fork Brazos River at Justiceburg	1/40-11/61	DM_JU = 0.201 * DM_AS	0.682
B-9	DM_AS	Double Mountain Fork Brazos R. near Aspermont	None	-	-
B-10	NC_KN	North Croton Creek near Knox City	1/40-9/65; 10/86-1997	KC_KN = 0.154 * SF_AS	0.615
B-11	BR_SE	Brazos River at Seymour	None	-	-
B-12	MS_MN	Millers Creek near Munday	1/40-6/63	MS_MN = 0.050 * [(CF_FG-(0.56482*CF_NU)]	0.695
B-13	CF_RO	Clear Fork Brazos River near Roby	1/40-12/61	CF_RO = 0.061 * DM_AS	0.346

Table 3-1, continued

No.	ID	Name	Missing Period	Fill Relationship Used	R^2 for Fill Rel.
B-14	CF_HA	Clear Fork. Brazos River at Hawley	1/40-9/67; 10/89-1997	CF_HA = 0.464 * CF_NU	0.670
B-15	MU_HA	Mulberry Creek near Hawley	1/40-9/67; 10/89-1997	MU_HA = 0.081 * CF_NU	0.651
B-16	CF_NU	Clear Fork Brazos River at Nugent	None	-	-
B-17	CA_ST	California Creek near Stamford	1/40-9/62	CA_ST = 0.156 * CF_FG	0.741
B-18	CF_FG	Clear Fork Brazos River at Fort Griffin	None	-	-
B-19	HC_AL	Hubbard Creek below Albany	1/40-9/51	HC_AL = 0.241 * CF_EL	0.738
			10/51-4/55	HC_AL = 0.179 * [BR_SB– (0.57884 * BR_SE)- (0.62646*CF_FG)]	0.543
			5/55-9/66	HC_AL = 0.600 * HC_BR	0.864
B-20	BS_BR	Big Sandy Creek above Breckenridge	1/40-9/51	BS_BR = 0.121 * [CF_EL- (0.68637*CF_FG)]	0.639
			10/51-4/55	BS_BR = 0.067 * [BR_SB– (0.57884 * BR_SE)- (0.62646*CF_FG)]	0.507
			5/55-2/62	BS_BR = 0.193 * HC_BR	0.694
B-21	HC_BR	Hubbard Creek near Breckenridge	1/40-9/51	HC_BR = 0.586 * [CF_EL- (0.68637*CF_FG)]	0.846
			10/51-4/55	HC_BR = 0.285 * [BR_SB– (0.57884 * BR_SE)- (0.62646*CF_FG)]	0.699
B-22	CF_EL	Clear Fork Brazos River at Eliasville	10/51-9/61; 10/82-1997	CF_EL = 0.604 * [BR_SB– (0.57884 * BR_SE)]	0.907
B-23	BR_SB	Brazos River near South Bend	None	-	-
B-24	GH_GH	Lake Graham near Graham	5/62-9/63; 6/70-8/71; 5/73-7/74; 8/77-2/79; 8/82-9/84; 7/89-12/89; 11/96-12/97	GH_GH = 0.305 * [BR_PP - (0.97733 * BR_SB)]	0.569
B-25	CC_IV	Big Cedar Creek near Ivan	1/40-11/64; 10/89-1997	CC_IV = 0.086 * [BR_PP - (0.97733 * BR_SB)]	0.613
B-26	SH_GR	Brazos River at Morris Sheppard Dam near Graford	1/40-9/76	SH_GR = 0.991 * BR_PP	0.990
B-27	BR_PP	Brazos River near Palo Pinto	None	-	-
B-28	PP_SA	Palo Pinto Creek near Santo	1/40-4/51; 10/76-1997	PP_SA = 0.172 * [BR_GR - (0.96071 * BR_PP)]	0.753
B-29	BR_DE	Brazos River near Dennis	1/40-4/68	BR_DE = 0.904 * BR_GR	0.984

Table 3-1, continued

No.	ID	Name	Missing Period	Fill Relationship Used	R^2 for Fill Rel.
B-30	BR_GR	Brazos River near Glen Rose	None	-	-
B-31	PA_GR	Paluxy River at Glen Rose	1/40-5/47	PA_GR = 0.190 * [BR_AQ - (0.97801 * BR_GR)]	0.696
B-32	NR_BL	Nolan River at Blum	1/40-11/47; 3/87-9/92; 10/96-9/97	NR_BL = 0.230 * [BR_AQ - (0.97801 * BR_GR)]	0.635
B-33	BR_AQ	Brazos River near Aquilla	None	-	-
B-34	AQ_AQ	Aquilla Creek near Aquilla	None	-	-
B-35	NB_HI	North Bosque River at Hico	1/40-12/61	NB_HI = 0.250 * NB_CL	0.796
B-36	NB_CL	North Bosque River near Clifton	None	-	-
B-37	NB_VM	North Bosque River At Valley Mills	1/40-7/59	NB_VM = 1.186 * NB_CL	0.962
B-38	MB_MG	Middle Bosque River near McGregor	1/40-7/59; 10/85-1997	MB_MG = 0.089 * [BR_WA - (0.98733 * BR_AQ)]	0.592
B-39	HG_CR	Hog Creek near Crawford	1/40-8/59; 10/85-1997	HG_CR = 0.045 * [BR_WA - (0.98733 * BR_AQ)]	0.788
B-40	BO_WA	Bosque River near Waco	1/40-9/59; 10/81-3/82; 7/82-1997	BO_WA = 0.609 * [BR_WA - (0.98733 * BR_AQ)]	0.922
B-41	BR_WA	Brazos River at Waco	None	-	-
B-42	BR_HB	Brazos River near Highbank	1/40-9/65	BR_HB = 0.801 * BR_WA + 0.191 * BR_BR	0.986
B-43	LE_DL	Leon River near De Leon	1/40-8/60 & 10/86-9/91	LE_DL = 0.426 * LE_HS	0.830
			10/91-9/96 & 10/97-1997	LE_DL = 0.324 * LE_HM	0.674
B-44	SA_DL	Sabana River near De Leon	1/40-8/60; 10/86-9/91	SA_DL = 0.268 * LE_HS	0.913
			9/91-1997	SA_DL = 0.209 * LE_HM	0.710
B-45	LE_HS	Leon River near Hasse	10/91-1997	LE_HS = 0.941 * LE_HM	0.872
B-46	LE_HM	Leon River near Hamilton	1/40-9/50	LE_HM = 1.086 * LE_HS	0.870
			10/50-8/60	LE_HM = 0.493 * LE_HS + 0.424 * LE_GT	0.967
B-47	LE_GT	Leon River at Gatesville	1/40-9/50	LE_GT = 0.588 * LE_HS + 0.357 * LE_BE	0.960
B-48	CO_PI	Cowhouse Creek at Pidcoke	1/40-9/50	CO_PI = 0.193 * [LE_BE - (0.59655 * LE_HS)]	0.879
B-49	LE_BE	Leon River near Belton	None	-	-
B-50	LA_KE	Lampasas River near Kempner	1/40-9/62	LA_KE = 0.566 * LA_YO	0.915
B-51	LA_YO	Lampasas River at Youngsport	10/80-1997	LA_YO = 1.648 * LA_KE	0.911

Table 3-1, continued

No.	ID	Name	Missing Period	Fill Relationship Used	R^2 for Fill Rel.
B-52	LA_BE	Lampasas River near Belton	1/40-1/63	LA_BE = 1.087 * LA_YO	0.987
			11/89-1997	LA_BE = 0.290 * LR_LR	0.945
B-53	LR_LR	Little River near Little River	1/40-7/62	LR_LR = 1.158 * (LA_YO + LE_BE)	0.985
B-54	NG_GE	North Fork San Gabriel River near Georgetown	1/40-6/68	NG_GE = 0.565 * GA_GE	0.970
B-55	SG_GE	South Fork San Gabriel River at Georgetown	1/40-11/67	SG_GE = 0.358 * GA_GE	0.931
B-56	GA_GE	San Gabriel River at Georgetown	10/73-10/84; 12/84-5/85; 10/85-12/85; 2/86-3/86; 5/86-6/86; 9/86-1997	GA_GE = 1.115 * (NG_GE + SG_GE)	0.984
B-57	GA_LA	San Gabriel River at Laneport	1/40-9/65	GA_LA = 1.818 * GA_GE	0.915
B-58	LR_CA	Little River at Cameron	None	-	-
B-59	BR_BR	Brazos River near Bryan	10/93-1997	BR_BR = 1.099 * (BR_HB + LR_CA)	0.990
B-60	MY_DB	Middle Yegua Creek near Dime Box	1/40-7/62	MY_DB = 0.178 * YC_SO	0.783
B-61	EY_DB	East Yegua Creek near Dime Box	1/40-7/62	EY_DB = 0.186 * YC_SO	0.850
B-62	YC_SO	Yegua Creek near Somerville	9/91-1997	YC_SO = 4.772 * EY_DB	0.848
B-63	DC_LY	Davidson Creek near Lyons	1/40-9/62	DC_LY = 0.204 * YC_SO	0.767
B-64	NA_GR	Navasota River above Groesbeck	1/40-5/78	NA_GR = 0.265 * NA_EA	0.794
B-65	BG_FR	Big Creek near Freestone	1/40-6/78	BG_FR = 0.099 * NA_EA	0.895
B-66	NA_EA	Navasota River near Easterly	None	-	-
B-67	NA_BR	Navasota River near Bryan	1/40-12/50; 10/94-1997	NA_BR = 1.228 * NA_EA	0.941
B-68	BR_HE	Brazos River near Hempstead	None	-	-
B-69	MC_BL	Mill Creek near Bellville	1/40-7/63	MC_BL = 0.622 * YC_SO	0.693
			10/93-12/96	MC_BL = 2.633 * CY_CY (CY_CY is Cypress Bayou at Cypress in the San Jacinto Basin [37])	0.651
			1/97-12/97	MC_BL = 2.566 * DC_LY	0.621
B-70	BR_RI	Brazos River at Richmond	None	-	-

Table 3-1, continued

No.	ID	Name	Missing Period	Fill Relationship Used	R^2 for Fill Rel.
B-71	BG_NE	Big Creek near Needville	1/40-5/47; 7/50-3/52	BG_NE = 0.297 * BR_HO (BR_HO is Brays Bayou at Houston in the San Jacinto Basin [37])	0.619
B-72	BR_RO	Brazos River at Rosharon	1/40-3/67; 10/80-4/84	BR_RO = 1.036 * BR_RI	0.994
B-73	BR_GM	Brazos River at Gulf of Mexico	1/40-12/97	BR_GM = 0.98344 * BR_RO + $(DA_{BR\_GM} / DA_{BG\_NE})$ * BG_NE	N/A
BSJ-1	CL_PE	Clear Creek near Pearland	1/40-7/44, 11/44-2/46, 11/46-3/47, 1/60-3/63, 10/92-12/96	CL_PE = 0.299 * BR_HO (BR_HO is Brays Bayou at Houston in the San Jacinto Basin [37])	0.630
			1/97-12/97	CL_PE = 0.326 * CB_AL	0.573
BSJ-2	CB_AL	Chocolate Bayou near Alvin	1/40-12/40	CB_AL = 0.733 * BR_HO (BR_HO is Brays Bayou at Houston in the San Jacinto Basin [37])	0.395
			1/44-7/44; 11/44-2/46; 11/46-12/46	CB_AL = 0.716 * Texas Rainfall / Runoff Model	0.686
			9/44-10/44; 3/46; 5/46-10/46; 2/58-2/59	CB_AL = 2.478 * CL_PE	0.706
BSJ-3	SJ_GB	San Jacinto-Brazos Coastal Basin at Galveston Bay	1/40-12/97	SJ_GB = $[(DA_{SJ\_GB} – DA_{CL\_PE} – DA_{CB\_AL}) / (DA_{CL\_PE} + DA_{CB\_AL})]$ * (CB_AL + CL_PE) + 0.98899 * CL_PE + 0.99427 * CB_AL	N/A
BSJ_4	SJ_GM	San Jacinto-Brazos Coastal Basin at the Gulf of Mexico	1/40-12/97	SJ_GM = $[DA_{SJ\_GM} / (DA_{CL\_PE} + DA_{CB\_AL})]$ * (CL_PE + CB_AL)	N/A

Comparison of Naturalized Flows to Previous Studies

There have been several previous studies for which estimates of naturalized flows have been developed for the Brazos River Basin, including the U.S. Study Commission work [(13)], the Texas Natural Resource Conservation Commission Legacy Water Availability Model [(14)], and a study done in the late 1980s by Texas A&M University [(15)]. In this section of the report, estimates of naturalized flows from those studies are compared with the estimates developed for the current study.

Data from different studies were compared using linear regressions with zero intercept (which show how much of the variation in one set of data can be explained by the variation in the other) and using double mass curves (which show the variation in the relationship between sets of data over time).

In the comparisons, data for a control point from two different studies are assumed to match closely if the following conditions are met:

- The R^2 value for a linear regression with a zero intercept exceeds 0.95 (which means that the data vary consistently), and
- The slope of the linear regression is between 0.95 and 1.05 (which means that the values are nearly the same as well as varying consistently), and
- The slope of the double mass curve is between 0.95 and 1.05.

4.1 U.S. Study Commission

The U.S. Study Commission (USSC) completed a major study of Texas water resources in 1960. The study included development of naturalized streamflows for several Texas basins, including the Brazos, for 1940 through 1957 [(13)]. Table F-1 in Appendix F summarizes the comparison between naturalized flows from the USSC and naturalized flows from the current study for common control points. Appendix F also includes scatter plots and double mass curves for several key points. (The comparison with the USSC is based on annualized values because only annualized values were available for gages in the USSC report.)

In general, the USSC naturalized flows match those developed for this study well. There are two areas in which the flows compare well using traditional statistical measures but the naturalized flows in the current study are significantly higher than naturalized flow values than the USSC:

- The Clear Fork of the Brazos River at Nugent and Fort Griffin
- The main stem of the Brazos River downstream from Possum Kingdom Reservoir as far as Waco.

There is no clear explanation for the discrepancy in flows between the two studies.

Figures 4-1 through 4-5 show the double mass curves for the comparison between the current study and the USSC for the following key gages:

- Brazos River at South Bend
- Brazos River at Palo Pinto
- Brazos River at Waco
- Little River at Cameron
- Brazos River at Richmond

At all of the main stem gages, the values from the current study are somewhat higher, with the most pronounced differences at Palo Pinto and Waco. For all of the main stem gages, the double mass curves show a noticeable difference in the last years of the common period, which correspond to the drought of the 1950s. The current study shows more naturalized flow in the 1950s than did the USSC report.

4.2 Texas Natural Resource Conservation Commission Legacy Water Availability Model

The Texas Natural Resource Conservation Commission Legacy Water Availability Model for the Brazos River Basin (Legacy WAM) was developed in the 1980s [14]. The Legacy WAM included flows for 1940 through 1976. Table G-1 in Appendix G summarizes the comparison between naturalized flows from the Legacy WAM and the current study for primary control points used in both studies. Appendix G also includes scatter plots and double mass curves for some key control points.

Figures 4-1 through 4-5 show the comparison of the double mass curves between the current study and the Legacy WAM and the current study and the USSC.

The naturalized flows from the current study do not match the TNRCC Legacy WAM values as consistently as they do the USSC values. There are several points with poor R^2 values. They are all primary control points with incomplete records, and the fill relationship used by TNRCC differed from those used in this study. For the period of gaged records, the R^2 values are good for all points except the San Gabriel River at Laneport. No clear explanation is available for this discrepancy. However, the slopes of the linear regressions and double mass curves indicate that the data do not match for many control points. In general, values for the Clear Fork are lower in the current study than in the Legacy WAM, as are values on the main stem between South Bend and Aquilla. It is interesting to note that the current study disagrees with the USSC results in the opposite direction in each of these areas.

It should also be noted that some of the primary control points used in this study were not used as primary control points in the Legacy WAM. Flows calculated in the Legacy WAM at these points often compare very poorly with the current study, and it appears that historical flow data for these points were not considered in the Legacy WAM.

4.3 Texas A&M Model of the Brazos River Basin

The Texas A&M model of the Brazos River Basin (A&M WAM) was developed in the late 1980s [15]. The A&M WAM used Legacy WAM naturalized flows for 1940 through 1976 and extended the flows through 1984. Table H-1 in Appendix H summarizes the comparison between naturalized flows for the current study and the A&M WAM for three control points. Appendix H also includes scatter plots and double mass curves for some of these control points. The flows compare very well for the Brazos River at Richmond and the Little River at Cameron. The comparison is poor for the Brazos River at Aquilla. No apparent reason is available for this poor correlation.

Figure 4-1. Double Mass Comparison of Annual Naturalized, USSC, and TNRCC Legacy WAM Flows for the Brazos River at South Bend

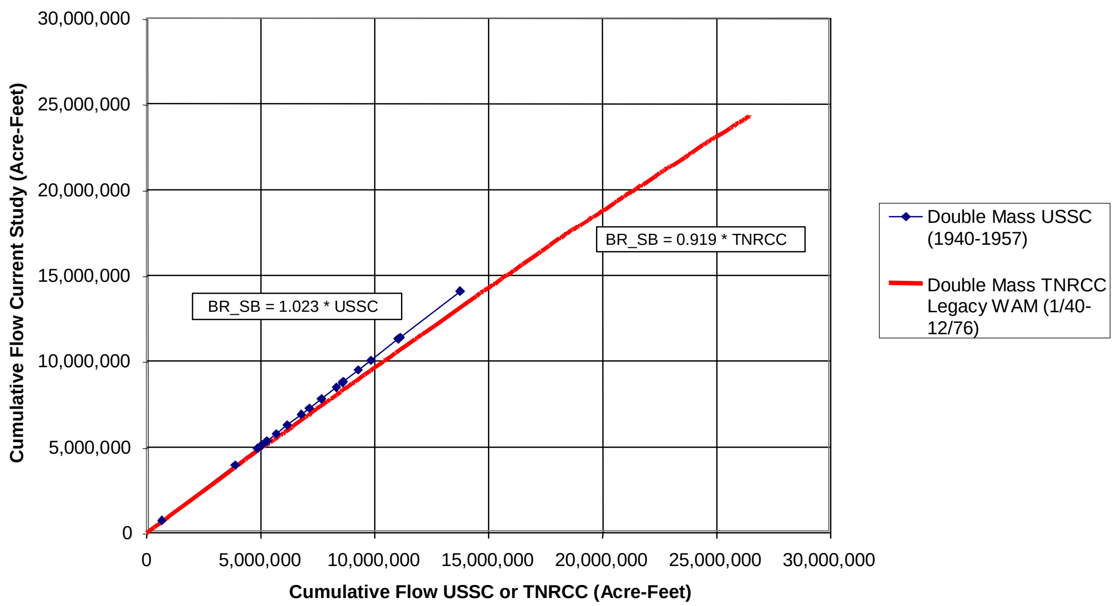


Figure 4-2. Double Mass Comparison of Annual Naturalized, USSC, and TNRCC Legacy WAM Flows for the Brazos River at Palo Pinto

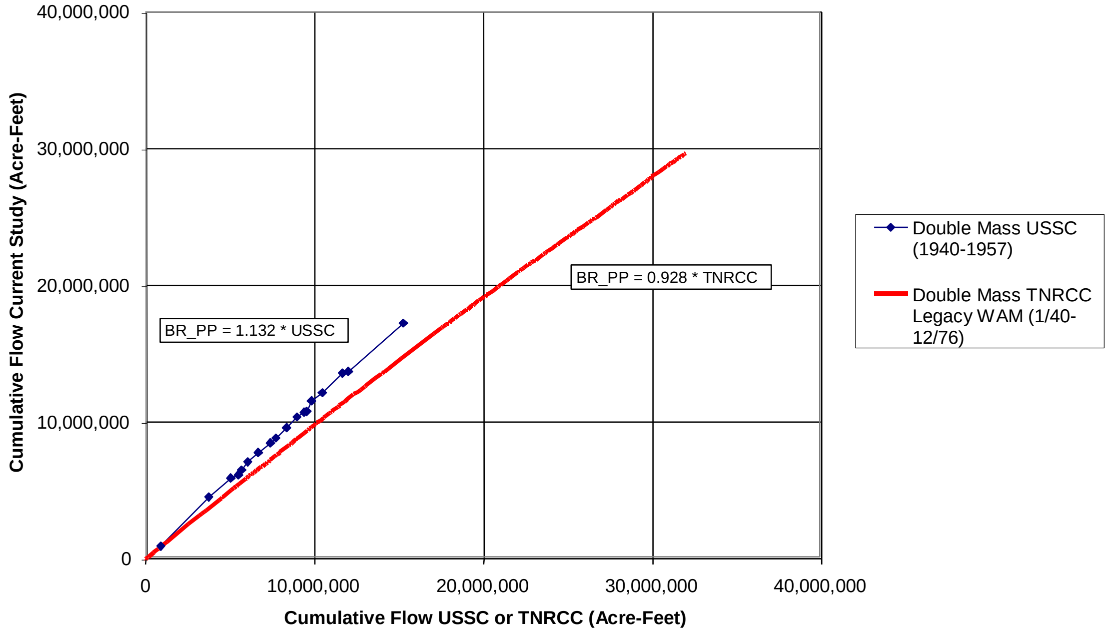


Figure 4-3. Double Mass Comparison of Annual Naturalized, USSC, and TNRCC Legacy WAM Flows for the Brazos River at Waco

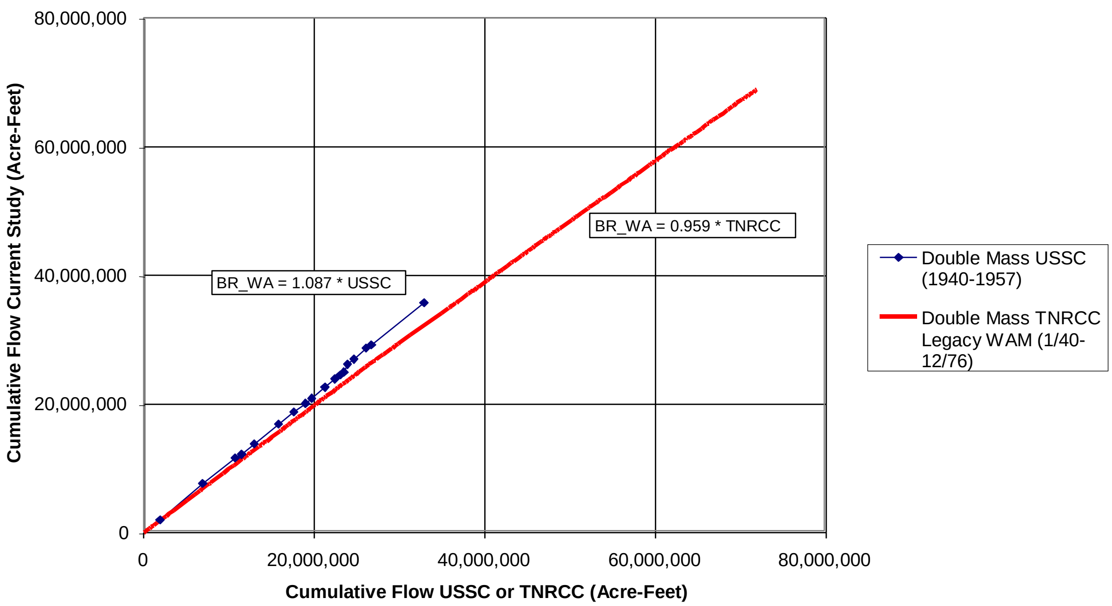


Figure 4-4. Double Mass Comparison of Annual Naturalized, USSC, and TNRCC Legacy WAM Flows for the Little River at Cameron

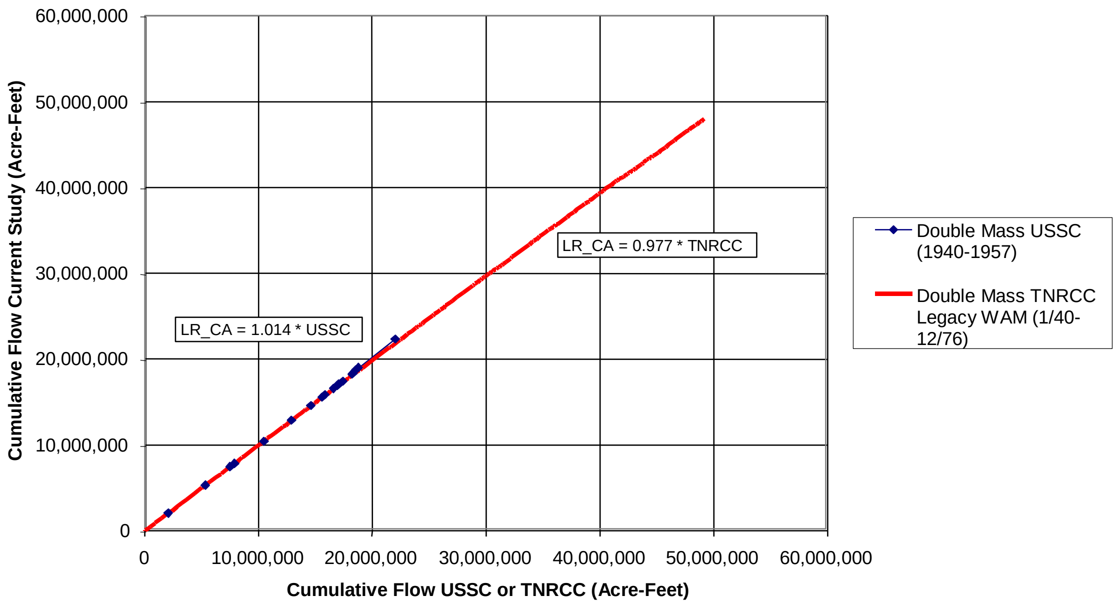
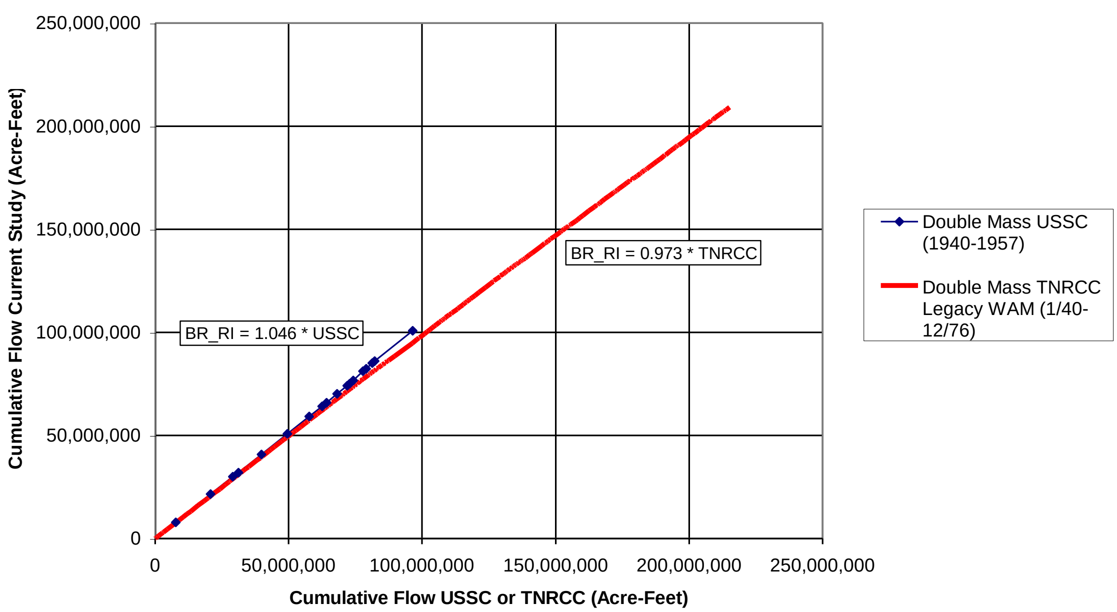


Figure 4-5. Double Mass Comparison of Annual Naturalized, USSC, and TNRCC Legacy WAM Flows



Comparison of Naturalized Flows with Historical Gaged Flows

Table I-1 in Appendix I is a comparison of historical and naturalized monthly flows for all primary control points in the Brazos River Basin. The changes from naturalized to historical flows for some key gages are described below.

Brazos River at South Bend. This gage is upstream of all the major main stem reservoirs, although there are several smaller reservoirs upstream. In general, historical low flows (minimum and 10^{th} percentiles) are reduced in most months from natural conditions, but 25^{th} percentile and higher historical flows are very near to naturalized conditions.

Brazos River near Palo Pinto. This is the gage immediately downstream from Morris Sheppard Dam and Possum Kingdom Lake. In general, historical low flows (minimum and 10^{th} percentile) at this control are significantly higher than naturalized flows, with the exception of 10^{th} percentile flows in May and June, which are lower than naturalized flows. Median historical flows are lower than naturalized flows in the spring and higher in the winter and summer.

Brazos River at Waco. Historical flows at Waco tend to be lower than naturalized flows in the spring and higher in the remainder of the year, especially in the fall.

Little River at Cameron. In general, historical and naturalized flows are relatively close at this gage, with historical flows tending to be somewhat lower.

Brazos River at Richmond. Historical and naturalized flows tend to be relatively close at Richmond, which is near the mouth of the river. However, historical low flows are higher than naturalized flows in the summer.

Review of Flows for Internal Consistency

Table J-1 in Appendix J shows the monthly naturalized flows developed in this study for each primary control point in the Brazos River Basin and the incremental flows between control points (accounting for losses). Table 6-1 shows the naturalized runoff per square mile for each control point in acre-feet per month for the 1940-1997 study period. In general, the runoff per square mile increases from upstream to downstream, from north to south, and from west to east, which is appropriate in Texas.

Table K-1 in Appendix K shows the statistics from regression and double mass comparisons of gages with each other. In this comparison, it is desirable to have high R^2 values, indicating that the flows vary consistently, and to have slopes of the linear regression and the double mass curve consistent with expected differences in flow.

In general, Appendices J and K show good internal consistency among the flow values.

Table 6-1. Unit Runoff for Primary Control Points

No.	ID	Name	Contributing Drainage Area (Sq. Mi.)	Incremental Drainage Area (Sq. Mi.)	Overall Unit Runoff (Ac-Ft /Mo/Sq. Mi.)	Incremental Unit Runoff (Ac-Ft/Mo/ Sq. Mi.)
B-1	RW_PL	Running Water Draw at Plainview	382	382	0.5	0.5
B-2	WR_SP	White River Reservoir near Spur	689	307	2.0	4.5
B-3	DU_GI	Duck Creek near Girard	279	279	3.0	3.0
B-4	SF_PE	Salt Fork Brazos River near Peacock	1,985	1,017	2.3	2.9
B-5	CR_JA	Croton Creek near Jayton	290	290	3.6	3.6
B-6	SF_AS	Salt Fork Brazos River near Aspermont	2,496	221	2.6	7.8
B-7	BS_LU	Buffalo Springs Lake near Lubbock	236	236	6.0	6.0
B-8	DM_JU	Double Mountain Fork Brazos River at Justiceburg	244	244	7.6	7.6
B-9	DM_AS	Double Mountain Fork Brazos River near Aspermont	1,864	1,384	4.8	5.5
B-10	NC_KN	North Croton Creek near Knox City	251	251	4.3	4.3
B-11	BR_SE	Brazos River at Seymour	5,972	1,361	3.5	8.9

Table 6-1, continued

No.	ID	Name	Contributing Drainage Area (Sq. Mi.)	Incremental Drainage Area (Sq. Mi.)	Overall Unit Runoff (Ac-Ft /Mo/Sq. Mi.)	Incremental Unit Runoff (Ac-Ft/Mo/ Sq. Mi.)
B-12	MS_MN	Millers Creek near Munday	104	104	4.7	4.7
B-13	CF_RO	Clear Fork Brazos River near Roby	228	228	2.6	2.6
B-14	CF_HA	Clear Fork Brazos River at Hawley	1,416	1,188	2.7	2.8
B-15	MU_HA	Mulberry Creek near Hawley	205	205	3.2	3.2
B-16	CF_NU	Clear Fork Brazos River at Nugent	2,199	578	3.6	7.1
B-17	CA_ST	California Creek near Stamford	478	478	4.8	4.8
B-18	CF_FG	Clear Fork Brazos River at Fort Griffin	3,988	1,311	3.7	6.5
B-19	HC_AL	Hubbard Creek below Albany	613	613	7.8	7.8
B-20	BS_BR	Big Sandy Creek above Breckenridge	280	280	6.9	6.9
B-21	HC_BR	Hubbard Creek near Breckenridge	1,089	196	7.4	11.2
B-22	CF_EL	Clear Fork Brazos River at Eliasville	5,697	620	4.5	14.3
B-23	BR_SB	Brazos River near South Bend	13,107	1334	4.2	14.1
B-24	GH_GH	Lake Graham near Graham	221	221	13.5	13.5
B-25	CC_IV	Big Cedar Creek near Ivan	97	97	11.6	11.6
B-26	SH_GR	Brazos River at Morris Sheppard Dam near Graford	14,030	605	4.7	13.8
B-27	BR_PP	Brazos River near Palo Pinto	14,245	215	4.7	8.1
B-28	PP_SA	Palo Pinto Creek near Santo	573	573	9.3	9.3
B-29	BR_DE	Brazos River near Dennis	15,671	853	5.3	14.4
B-30	BR_GR	Brazos River near Glen Rose	16,252	581	5.7	19.4
B-31	PA_GR	Paluxy River at Glen Rose	410	410	11.9	11.9
B-32	NR_BL	Nolan River at Blum	282	282	19.9	19.9
B-33	BR_AQ	Brazos River near Aquilla	17,678	734	6.5	18.3
B-34	AQ_AQ	Aquilla Creek near Aquilla	308	308	24.1	24.1
B-35	NB_HI	North Bosque River at Hico	359	359	10.4	10.4
B-36	NB_CL	North Bosque River near Clifton	968	609	14.0	17.4
B-37	NB_VM	North Bosque River At Valley Mills	1,146	178	14.8	23.6
B-38	MB_MG	Middle Bosque River near McGregor	182	182	25.3	25.3
B-39	HG_CR	Hog Creek near Crawford	78	78	27.5	27.5
B-40	BO_WA	Bosque River near Waco	1,656	250	18.0	33.5
B-41	BR_WA	Brazos River at Waco	20,007	365	8.1	32.1

Table 6-1, continued

No.	ID	Name	Contributing Drainage Area (Sq. Mi.)	Incremental Drainage Area (Sq. Mi.)	Overall Unit Runoff (Ac-Ft /Mo/Sq. Mi.)	Incremental Unit Runoff (Ac-Ft/Mo/ Sq. Mi.)
B-42	BR_HB	Brazos River near Highbank	20,870	863	9.3	40.1
B-43	LE_DL	Leon River near De Leon	479	479	9.8	9.8
B-44	SA_DL	Sabana River near De Leon	264	264	11.1	11.1
B-45	LE_HS	Leon River near Hasse	1,261	518	9.3	10.8
B-46	LE_HM	Leon River near Hamilton	1,891	630	7.3	10.2
B-47	LE_GT	Leon River at Gatesville	2,342	451	9.2	17.6
B-48	CO_PI	Cowhouse Creek at Pidcoke	455	455	14.2	14.2
B-49	LE_BE	Leon River near Belton	3,542	745	11.9	19.9
B-50	LA_KE	Lampasas River near Kempner	818	818	12.2	12.2
B-51	LA_YO	Lampasas River at Youngsport	1,240	422	14.0	17.8
B-52	LA_BE	Lampasas River near Belton	1,321	81	14.7	26.8
B-53	LR_LR	Little River near Little River	5,228	365	13.5	25.6
B-54	NG_GE	North Fork San Gabriel River near Georgetown	248	248	19.5	19.5
B-55	SG_GE	South Fork San Gabriel River at Georgetown	133	133	22.7	22.7
B-56	GA_GE	San Gabriel River at Georgetown	405	24	21.5	35.9
B-57	GA_LA	San Gabriel River at Laneport	738	333	21.4	21.5
B-58	LR_CA	Little River at Cameron	7,065	1,099	15.5	23.0
B-59	BR_BR	Brazos River near Bryan	29,949	2,014	11.2	19.5
B-60	MY_DB	Middle Yegua Creek near Dime Box	236	236	13.9	13.9
B-61	EY_DB	East Yegua Creek near Dime Box	244	244	14.8	14.8
B-62	YC_SO	Yegua Creek near Somerville	1,009	529	18.5	22.5
B-63	DC_LY	Davidson Creek near Lyons	195	195	20.3	20.3
B-64	NA_GR	Navasota River above Groesbeck	240	240	29.0	29.0
B-65	BG_FR	Big Creek near Freestone	97	97	27.7	27.7
B-66	NA_EA	Navasota River near Easterly	968	631	27.8	27.5
B-67	NA_BR	Navasota River near Bryan	1,454	486	24.1	17.5
B-68	BR_HE	Brazos River near Hempstead	34,314	1,707	13.0	37.6
B-69	MC_BL	Mill Creek near Bellville	376	376	33.2	33.2
B-70	BR_RI	Brazos River at Richmond	35,441	751	13.8	55.8
B-71	BG_NE	Big Creek near Needville	43	43	49.7	49.7
B-72	BR_RO	Brazos River at Rosharon	35,773	289	14.2	85.6
B-73	BR_GM	Brazos River at Gulf of Mexico	35,931	158	14.2	49.7

Table 6-1, continued

No.	ID	Name	Contributing Drainage Area (Sq. Mi.)	Incremental Drainage Area (Sq. Mi.)	Overall Unit Runoff (Ac-Ft /Mo/Sq. Mi.)	Incremental Unit Runoff (Ac-Ft/Mo/ Sq. Mi.)
BSJ-1	CL_PE	Clear Creek near Pearland	39	39	61.4	61.4
BSJ-2	CB_AL	Chocolate Bayou near Alvin	88	88	72.3	72.3
BSJ-3	SJ_GB	San Jacinto-Brazos Coastal Basin at Galveston Bay	1,145	1,018	69.2	69.3
BSJ-4	SJ_GM	San Jacinto-Brazos Coastal Basin at the Gulf of Mexico	293	293	69.2	69.2

Appendix A
List of References

(1) U.S. Geological Survey: *Water Resources Data, Texas*, published annually at Austin, Texas. Prior to 1960, these records were published as USGS *Water Supply Papers*.

(2) Freese and Nichols, Inc., and HDR, Inc.: *Appendix D of the Project Management Plan – Detailed Workplan for Developing Naturalized Streamflows in the Brazos and San Jacinto-Brazos River Basins*, prepared for the Texas Natural Resource Conservation Commission, Fort Worth, October 2000.

(3) HDR, Inc.: *Project Management Plan, Water Availability Modeling Project, Brazos River Basin and San Jacinto-Brazos Coastal Basin*, prepared for the Texas Natural Resource Conservation Commission, Austin, October 2000.

(4) Texas Natural Resource Conservation Commission: Electronic files and files of self-reported water use data from water right holders, Austin.

(5) Brazos River Authority: Electronic information on water sales and releases, Waco.

(6) Freese and Nichols, Inc.: Information from project files on releases from Brazos River Authority reservoirs for downstream users.

(7) U.S. National Oceanic and Atmospheric Administration, National Climatic Data Center: *Climatological Data, Texas*, Asheville, North Carolina. Previously published by the National Weather Service and the Weather Bureau.

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(10) Brazos River Authority: Spreadsheet of channel losses and travel times from BRA reservoirs to downstream points.

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(13) Bureau of Reclamation: *Runoff, Brazos River Basin*, prepared for the United States Study Commission – Texas, Austin, September 1960.

(14) Texas Natural Resource Conservation Commission: *TNRCC Water Availability Model Output*, compact disks recorded in June 1998.

(15) Ralph A. Wurbs, Carla E. Bergman, Patrick E. Carriere, and Brian Walls: *Hydrologic and Institutional Water Availability in the Brazos River Basin*, prepared for the Brazos River Authority, College Station, 1988.

(16) US Department of Agriculture, *Sediment Deposition in U.S. Reservoirs, Summary of Data Reported Through 1975*, Miscellaneous Publication Number 1362, February 1978.

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(19) Texas Natural Resource Conservation Commission, *Draft Technical Paper #3, Digital Elevation Modeling for the WAM and other TNRCC OWRM Projects*, July 1998.

(20) Texas Water Development Board, *Volumetric Survey of Lake Pat Cleburne*, prepared for the City of Cleburne, April 1988.

(21) Texas Water Development Board, *Volumetric Survey of Aquilla Lake*, prepared for the Brazos River Authority, January 1996.

(22) Texas Water Development Board: *Volumetric Survey of Belton Lake*, prepared for the Brazos River Authority, December 1994.

(23) Texas Water Development Board: *Volumetric Survey of Fort Phantom Hill Reservoir*, prepared for the City of Abilene, February 1994.

(24) Texas Water Development Board: *Volumetric Survey of Lake Granbury*, prepared for the Brazos River Authority, January 1994.

(25) Texas Water Development Board: *Volumetric Survey of Lake Limestone*, prepared for the Brazos River Authority, September 1993.

(26) Texas Water Development Board: *Volumetric Survey of Hubbard Creek Reservoir*, prepared for the West Central Texas Municipal Water District, May 1997.

(27) Texas Water Development Board: *Volumetric Survey of Lake Mexia*, prepared for the Bistone Municipal Water Supply District, August 1996.

(28) Texas Water Development Board: *Volumetric Survey of Miller's Creek Reservoir*, prepared for the North Central Texas Municipal Water Authority, July 1993.

(29) Texas Water Development Board: *Volumetric Survey of Proctor Lake*, prepared for the Brazos River Authority, March 1994.

(30) Texas Water Development Board: *Volumetric Survey of Squaw Creek Reservoir*, prepared for the Brazos River Authority and Texas Utilities, September 1997.

(31) Texas Water Development Board: *Volumetric Survey of Somerville Lake*, prepared for the Brazos River Authority, February 1996.

(32) Texas Water Development Board: *Volumetric Survey of Waco Lake*, prepared for the U. S. Army Corps of Engineers Fort Worth District, March 1995.

(33) Texas Water Development Board: *Volumetric Survey of White River Lake*, prepared for the White River Municipal Water Authority, June 1993.

(34) Texas Water Development Board: *Volumetric Survey of Lake Georgetown*, prepared for the Brazos River Authority, September 1995.

(35) Texas Water Development Board: *Volumetric Survey of Lake Granger*, prepared for the Brazos River Authority, December 1995.

(36) Texas Water Development Board: *Volumetric Survey of Stillhouse Hollow Lake*, prepared for the Brazos River Authority, August 1995.

(37) Espey, Padden Consultants, Inc., *Naturalized Streamflow Estimates in the Trinity, Trinity-San Jacinto, and Neches-Trinity River Basins*, February 2001.

(38) Texas Water Development Board, *Report 5807D Channel Gain and Loss Investigations, Texas Streams, 1918-1958*, April 1960.

Appendix E
Equations Considered to Fill Missing Data

Table E-1 shows the relationships considered for filling missing data for the primary control points. Double mass curves and linear regressions based on the period of overlapping data were considered for each control point. The best available relationship based on linear regression with a zero intercept was used to fit the missing data. The relationships used are not shaded.

Appendix F
Comparisons with U.S. Study Commission Flows

Table F-1 summarizes the comparison of naturalized flows from this study with those developed by the U.S. Study Commission for 1940-1957 [(13)]. The R^2 values shown in the table are for a linear regression with zero intercept. The data in the table are based on annual values, since that is all that was available from the U.S. Study Commission report. Figures F-1 through F-10 show scatter plots and double mass curves for five key points in the basin:

- Brazos River at South Bend
- Brazos River at Palo Pinto
- Brazos River at Waco
- Little River at Cameron
- Brazos River at Richmond.

Appendix G
Comparisons with TNRCC Legacy WAM Flows

Table G-1 summarizes the comparison of naturalized flows from this study with those developed for 1940-1976 for the Texas Natural Resource Conservation Commission Legacy Water Availability Model [13]. The R^2 values shown in the table are for a linear regression with zero intercept. Figures G-1 through G-10 show scatter plots and double mass curves for five key points in the basin:

- Brazos River at South Bend
- Brazos River at Palo Pinto
- Brazos River at Waco
- Little River at Cameron
- Brazos River at Richmond.

Appendix H
Comparisons with Texas A&M Model Flows

Table H-1 summarizes the comparison of naturalized flows from this study with those developed by Texas A&M for 1977-1984 [15]. The R^2 values shown in the table are for a linear regression with zero intercept. Figures H-1 through H-10 show scatter plots and double mass curves for key points in the basin.

- Brazos River at Aquilla
- Little River at Cameron
- Brazos River at Richmond.

Appendix I
Comparisons with Historical Gaged Flows

Table I-1 shows the historical and naturalized minimum, 10^{th} percentile, 25^{th} percentile, 50^{th} percentile (median), 75^{th} percentile, 90^{th} percentile, and maximum monthly flows for each primary control point. The values in Table I-1 are based on the period of historical flow data only, so the historical and naturalized values are directly comparable. (In other words, the naturalized data are not for the entire 1940-1997 period unless historical data are available for the entire period.)

Appendix J
Incremental Flows Accounting for Losses

Table J-1 shows the monthly naturalized flows developed in this study for each primary control point in the Brazos River Basin and the incremental flows between control points (accounting for losses). The incremental flow is defined as the flow that originates between the control points. The table also shows the average runoff per square mile per month and the incremental runoff per square mile per month for each primary control point. This allows comparison of water production between watersheds. In the derivation of incremental runoff, the losses to upstream flows are considered, so that the incremental flow is the true incremental flow produced in the intervening watershed.

Table J-1 includes some negative incremental flows between control points. Negative incremental flows occur occasionally at all gaged control points. In some cases, there are extended periods of relatively small negative incremental flows. These probably indicate that losses during some periods exceed the channel loss allowance made in the study. Examples occur at CF_FG between August 1943 and January 1944, at LE_BE between June 1954 and January 1955, at SF_PE between October 1964 and April 1965, at BO_WA between June and December 1977, at BR_PP between July and December 1987 and at NA_BR between August 1989 and January 1990. There are also some larger negative incremental flows that seem to be associated with the timing of flows – a large flow may reach the upstream gage in one month and reach the downstream gage in another. Examples occur at CF_FG between August and September of 1944, at BR_RI between April and May of 1953, at BR_HB between July and August 1966, at SH-GR between October and November 1976, and at BR_SE between June and July 1988.

Appendix K
Comparisons of Naturalized Flows with Each Other

Table K-1 summarizes the comparison of naturalized flows from this study with flows for other primary control points. The R^2 values shown in the table are for a linear regression with zero intercept.

Appendix L
Information on Flow Naturalization

Tables L-1 and L-2 list wastewater dischargers for which data were provided by TNRCC in the Brazos River and San Jacinto-Brazos Coastal Basins, respectively. Table L-3 summarizes the methodology used to determine reservoir content change. Table L-4 gives the location of evaporation and precipitation stations near major reservoirs. Where available, these data were used to calculate net reservoir evaporation. Where these data were not available, Texas Water Development Board quadrangle data were used. Table L-5 summarizes the methodology used to calculate net reservoir evaporation using the quadrangle data. Table L-6 gives the methodology used to calculate quadrangle runoff, which is a factor used to correct for the portion of rainfall that would have become runoff in the absence of a reservoir.

Appendix N
Comparison with TWDB Rainfall-Runoff Model

The TWDB used a rainfall-runoff model known as TxRR to estimate ungaged flows for Galveston Bay. Data for the entire coastal basin were provided by TWDB from January 1977 through September 1992. Ungaged flows were provided by TWDB for the entire basin from January 1977 through December 1997. Incomplete estimates of coastal basin runoff by TWDB from January 1941 through December 1976 were found in FNI files. These files included estimated flows at control point CB_AL prior to the establishment of a full-time flow gage at that location in 1947. These data were used to fill in missing data at that control point.

Figures N-1 through N-4 are comparisons of the Galveston Bay inflows from the San Jacinto-Brazos Coastal Basin with previous estimates by the TWDB. Figures N-1 and N-2 are scatter plot and double mass comparisons of total Galveston Bay inflows from the current study to the TxRR inflows. Figures N-3 and N-4 are comparisons of the ungaged flows. The month-by-month relationships in the scatter plots show a fair to good comparison between the two approaches, although in some months flows are substantially different. The long-term flow relationships illustrated in the double mass curves show that, over time, the two approaches give similar results.

Submitted to the Texas Water Digital Library on April 30, 2014, by Grant J. Gibson, P.G., WAM Project Coordinator, Texas Commission on Environmental Quality.