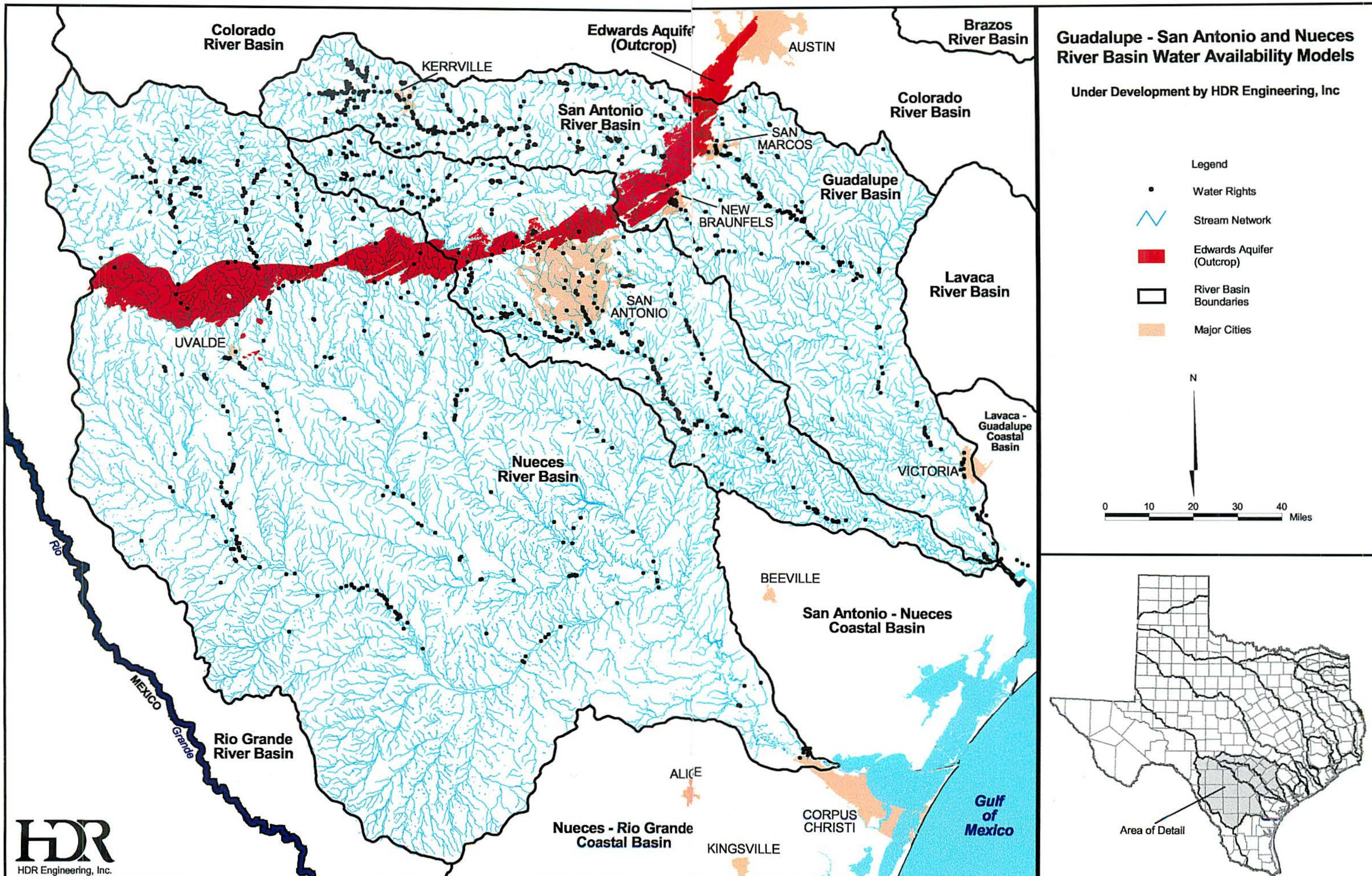
Edwards Aquifer Authority

Summary Information Regarding Historical Edwards Aquifer Recharge, Aquifer Modeling, and Recharge Enhancement Projects

HDR Engineering, Inc.

July 2, 1999


Guadalupe - San Antonio and Nueces River Basin Water Availability Models
Under Development by HDR Engineering, Inc
Legend
Water Rights
Stream Network
Edwards Aquifer (Outcrop)
River Basin Boundaries
Major Cities
N
0 10 20 30 40 Miles
Area of Detail
Colorado River Basin
Edwards Aquifer (Outcrop)
AUSTIN
Brazos River Basin
KERRVILLE
San Antonio River Basin
Colorado River Basin
SAN MARCOS
Guadalupe River Basin
NEW BRAUNFELS
Lavaca River Basin
SAN ANTONIO
UVALDE
Lavaca - Guadalupe Coastal Basin
VICTORIA
Nueces River Basin
Rio Grande
MEXICO
BEEVILLE
San Antonio - Nueces Coastal Basin
Rio Grande River Basin
ALICE
CORPUS CHRISTI
Gulf of Mexico
Nueces - Rio Grande Coastal Basin
KINGSVILLE
HDR Engineering, Inc.

Historical Edwards Aquifer Recharge

TRANS-TEXAS WATER PROGRAM

WEST CENTRAL STUDY AREA

PHASE 2

EDWARDS AQUIFER
RECHARGE UPDATE

San Antonio River Authority
San Antonio Water System
Edwards Aquifer Authority
Guadalupe-Blanco River Authority
Lower Colorado River Authority
Bexar Metropolitan Water District
Nueces River Authority
Canyon Lake Water Supply Corporation
Bexar-Medina-Atascosa Counties WCID No. 1
Texas Natural Resource Conservation Commission
Texas Parks and Wildlife Department
Texas Water Development Board

HDR Engineering, Inc.

March 1998

STATE OF TEXAS
SAMUEL KENT VAUGH
63487
REGISTERED
PROFESSIONAL ENGINEER

Samuel K. Vaugh
3/25/98

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EDWARDS AQUIFER RECHARGE UPDATE

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1.0 INTRODUCTION AND BACKGROUND

The 1990-96 historical period was one of extremes with respect to fluctuations in pumpage, water levels, and springflows associated with the Edwards Aquifer. Coming out of a drought in the late 1980's which resulted in record high annual pumpage (543,000 acft) in 1989, the Edwards Aquifer rose to a record high level of about 703 ft-msl recorded at the Bexar County Monitoring Well (J-17) in June, 1992 when pumpage fell to the lowest annual rate (327,000 acft) since 1973. Then, another drought cycle ensued resulting in significantly reduced springflows and severe water use restrictions during the summer of 1996. In addition to improved estimates of pumpage, the extremes experienced by the aquifer make the first half of the 1990's an excellent period for potential use in calibration of Edwards Aquifer models such as the GWSIM4 model developed by the Texas Water Development Board (TWDB).[1]

The TWDB staff is, in fact, engaged in recalibration and enhancement of the GWSIM4 model which has been applied extensively in the Trans-Texas Water Program, Edwards Aquifer litigation, and numerous technical and planning studies. This recalibration effort has been prompted by the availability of improved geological mapping in Hays, Comal, and Bexar Counties, installation of a precipitation (and streamflow) gaging network in the Edwards outcrop area, completion of aquifer divide studies, and ongoing water balance studies for Medina Lake and the Guadalupe River. In addition, estimates of historical Edwards Aquifer recharge have been developed by HDR Engineering, Inc. (HDR) in the course of studies sponsored by the Edwards Underground Water District[2] and Nueces River Authority.[3] Based on the 1934-89 historical period, HDR estimates differ significantly from those published by the U.S. Geological Survey[4] (USGS) in terms of both geographical and temporal distribution.

As the TWDB has expressed an interest in using the most recent historical data available in the recalibration effort and regional sponsors have expressed their concurrence, HDR has

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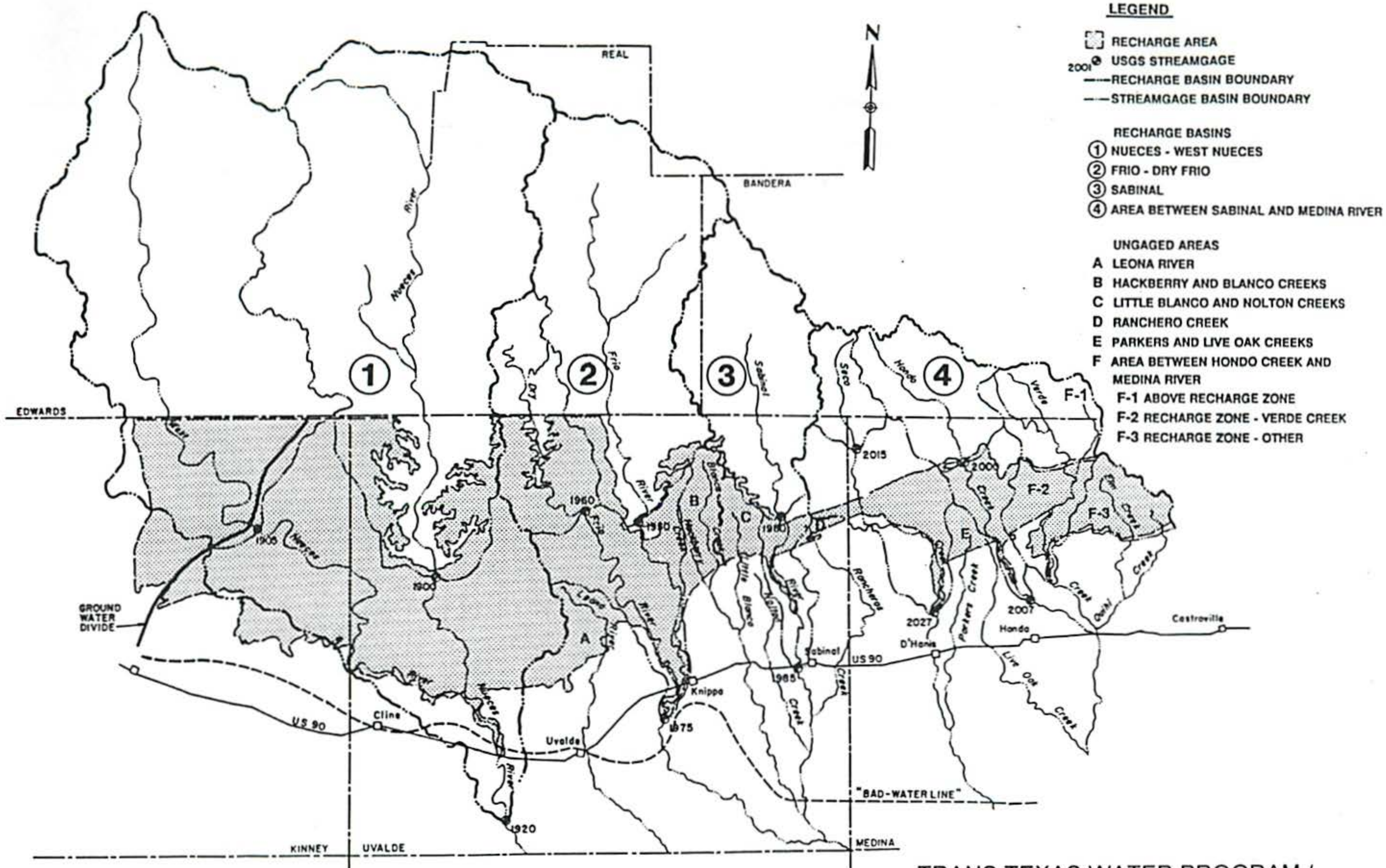
[1] TWDB, "Ground-water Resources and Model Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region," Report 239, October, 1979.
[2] HDR, "Guadalupe - San Antonio River Basin Recharge Enhancement Study," Vol. 2, Edwards Underground Water District, September, 1993.
[3] HDR, "Nueces River Basin Regional Water Supply Planning Study, Phase I," Vol. 2, Nueces River Authority, et al., May, 1991.
[4] USGS, "Recharge to and Discharge from the Edwards Aquifer in the San Antonio Area, Texas, 1996," http://txwww.cr.usgs.gov/reports/info/97/recharge1/index.html, April, 1997.

updated its recharge estimates to include the 1990-96 historical period and will provide them to the TWDB for consideration as an alternative to published USGS estimates. Estimates of Edwards Aquifer recharge have been developed for four recharge basins in the Nueces River Basin (Figure 1.0-1) and five recharge basins in the Guadalupe - San Antonio River Basin (Figure 1.0-2) for the 1990-96 historical period. The following sections of this report detail the data collection and refinement efforts prerequisite to recharge calculation, summarize the resulting estimates of Edwards Aquifer recharge in both historical and geographical contexts, and provide comparisons to published USGS estimates. Recommendations regarding opportunities for improvement of recharge estimates are included in Section 4.



APPROXIMATE SCALE

0 5 10 MILES

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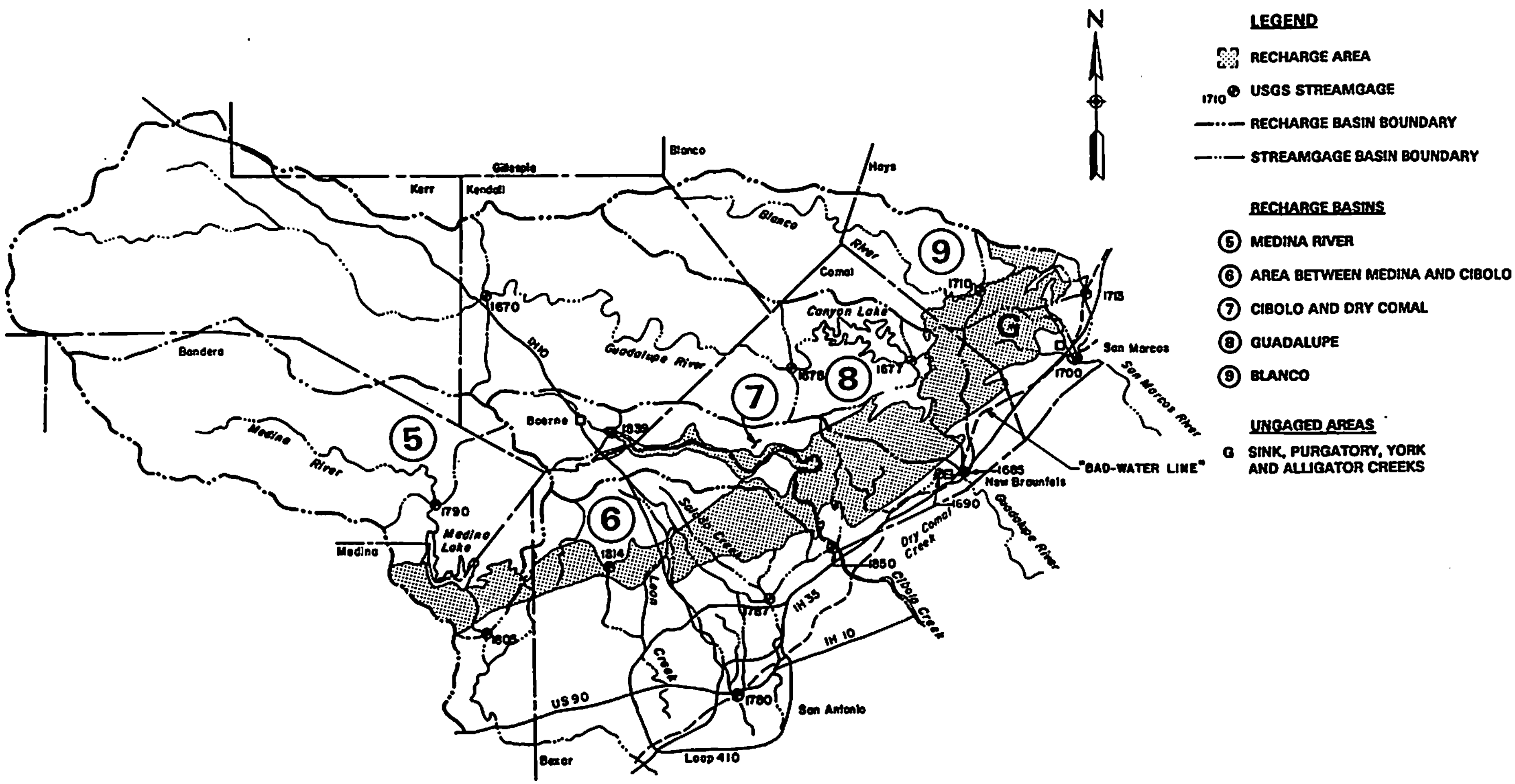
NUECES RIVER BASIN
EDWARDS AQUIFER
RECHARGE BASINS

FIGURE 1.0-1



EDWARDS AQUIFER
RECHARGE UPDATE

APPROXIMATE SCALE

0 10 20 Miles

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GSA RIVER BASIN
EDWARDS AQUIFER
RECHARGE BASINS

FIGURE 1.0-2

2.0 DATA COLLECTION AND REFINEMENT

The first step in the process of Edwards Aquifer recharge calculation was the collection of pertinent monthly hydrologic data sets including precipitation, streamflow, reservoir contents, surface water use, treated effluent volumes, and net evaporation for the 1990-96 historical period. Pertinent hydrologic data sets collected and primary sources are summarized as follows:

- Precipitation — National Weather Service, USGS, TWDB
- Streamflow — USGS
- Reservoir Contents — USGS, Bexar-Medina-Atascosa Counties WCID#1 (BMA), Blackwell, Carter & Associates, Inc. (BCA)
- Surface Water Use — Texas Natural Resource Conservation Commission (TNRCC, Office of the Water Master), USGS, BMA, BCA
- Treated Effluent Volumes — TNRCC
- Net Evaporation — BCA

Supplementary hydrologic data collected also includes monthly estimates of recharge for existing enhancement projects provided by the Edwards Aquifer Authority (EAA) and annual historical recharge by basin available from the USGS.

Once all pertinent information was in hand and prior to initiating recharge calculations, data sets from various sources were assembled and refined through review for consistency, estimation of unavailable data, areal precipitation computation, streamflow naturalization, and potential runoff calculation. Only one concern was noted regarding consistency of data for the 1990-96 period as compared with earlier years. This concern is associated with reported surface water use data provided by the TNRCC Water Master and its consistency with earlier data which was obtained from the TNRCC (prior to full implementation of the Water Master program). Figure 2.0-1 shows reported surface water use for four selected stream segments upstream of the Edwards Aquifer recharge zone for the 1980-96 period. While the apparent inconsistencies shown in Figure 2.0-1 may appear rather alarming, the potential effect on long-term average recharge estimates is minimal, so the surface water use data provided by the TNRCC Water Master was used directly. Areal precipitation computation, streamflow naturalization, and potential runoff calculation were all accomplished using techniques described in referenced studies.[1,2]

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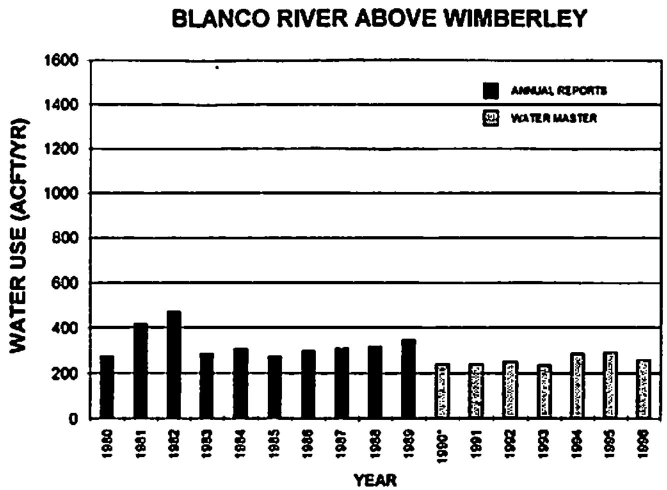
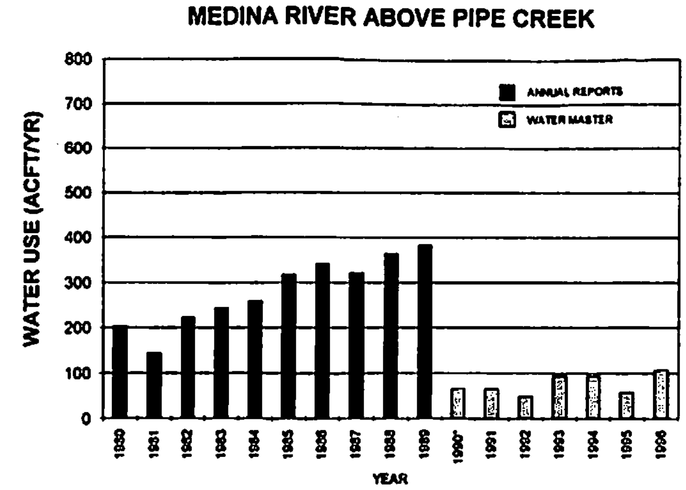
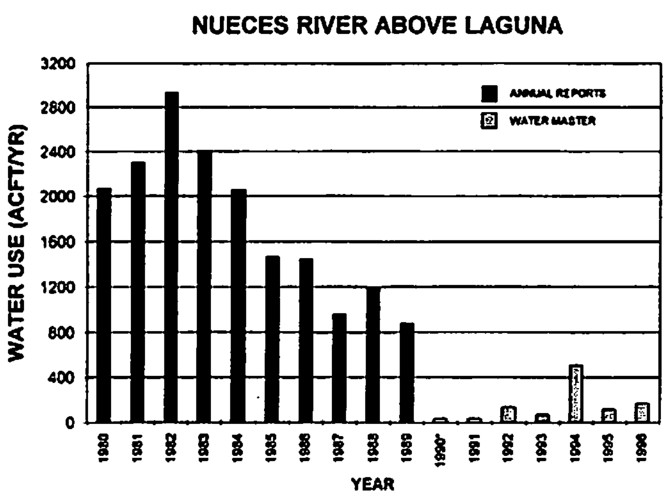
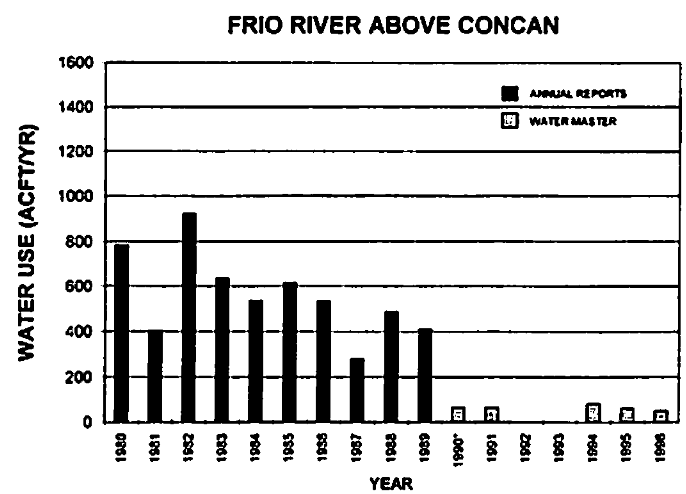
[1] HDR, Op. Cit., September, 1993.
[2] HDR, Op. Cit., May, 1991.









* No records of use available from TNRCC Water Master's office.
Water use assumed equal to that reported in 1991.

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REPORTED WATER USE COMPARISONS

FIGURE 2.0-1

3.0 RECHARGE SUMMARY AND COMPARISONS

Methodologies previously developed and applied by HDR in the computation of Edwards Aquifer recharge on a monthly timestep are described at length in studies prepared under the sponsorship of the Edwards Underground Water District[1] and the Nueces River Authority.[2] For consistency with these referenced studies, recharge estimates for the 1990-96 period have been computed using methodologies and assumptions identical to those previously applied. Resulting recharge estimates are summarized by major river basin in the following subsections and compared to those estimates prepared by the USGS. A comprehensive summary of historical Edwards Aquifer recharge estimates by river and recharge basin for the full 1934-96 historical period is included as Appendix A.

3.1 Nueces River Basin

The Nueces River Basin has been subdivided into four recharge basins identified in Figure 1.0-1 as the Nueces / West Nueces, Frio / Dry Frio, Sabinal, and the Area Between Sabinal and Medina Basin (which includes Seco, Hondo, and Verde Creek as well as several smaller tributary streams). In addition to naturally occurring recharge in the Nueces River Basin, the EAA (formerly EUWD) has constructed projects located on Seco, Parkers, and Verde Creek which serve to enhance recharge. Recharge associated with these projects was provided by the EAA for inclusion in the recharge basin summaries presented herein.

Figure 3.1-1 summarizes both HDR and USGS estimates of Edwards Aquifer recharge for each recharge basin within the Nueces River Basin for the 1990-96 historical period. Based on the full 1934-96 historical period, record high annual recharge volumes (432,412 acft) for the Sabinal River and the Seco, Hondo, and Verde Creek basins occurred in 1992 while a record low annual recharge volume of only 1,894 acft was computed for the Hondo Creek basin in 1996. It is readily apparently in Figure 3.1-1 that USGS recharge estimates in the wettest years are sometimes more than double those computed by HDR. There are several fundamental differences between certain recharge calculation procedures employed by the USGS and HDR,

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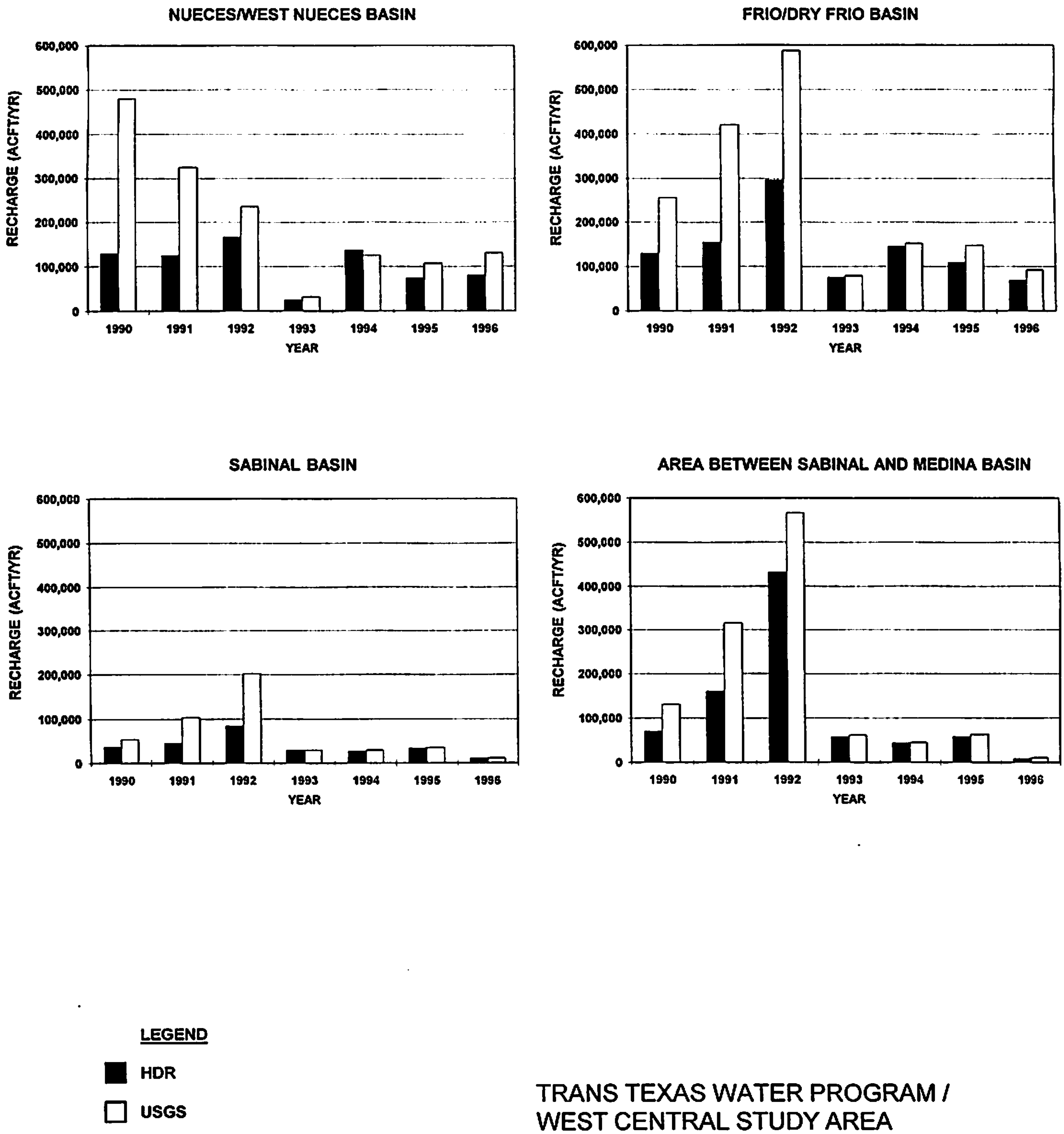
[1] HDR, Op. Cit., September, 1993.
[2] HDR, Op. Cit., May, 1991.



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ANNUAL EDWARDS AQUIFER RECHARGE COMPARISONS NUECES RIVER BASIN

FIGURE 3.1-1

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such as areal precipitation calculation, potential runoff estimation, and accounting for reported water rights diversions. The extreme difference in wet year estimates, however, is believed to be associated with the USGS application of "base flow curves" relating base flow upstream of the Edwards Aquifer outcrop to storage in the Edwards Plateau Aquifer contributing to base flow.[3]

3.2 Guadalupe - San Antonio River Basin

The Guadalupe - San Antonio River Basin has been subdivided into five recharge basins identified in Figure 1.0-2 as the Medina River, Area Between Medina and Cibolo (which includes San Geronimo, Helotes, Leon, and Salado Creek as well as several smaller tributary streams), Cibolo and Dry Comal, Guadalupe, and Blanco. In addition to naturally occurring recharge in the Guadalupe - San Antonio River Basin, the EAA has constructed one recharge project located on San Geronimo Creek and the Natural Resources Conservation Service (formerly Soil Conservation Service) has constructed numerous Flood Retardation Structures (FRS) in the Salado, Dry Comal, and Upper San Marcos basins which serve to enhance recharge. Recharge associated with the San Geronimo project was provided by the EAA for inclusion in the recharge basin summaries presented herein. Estimates of historical recharge enhancement associated with the FRS were computed by HDR using methodologies summarized in a previous study.[4]

Figure 3.2-1 summarizes both HDR and USGS estimates of Edwards Aquifer recharge for each recharge basin within the Guadalupe - San Antonio River Basin for the 1990-96 historical period. Based on the full 1934-96 historical period, record high annual recharge amounts for the Upper San Marcos River, Salado Creek, and combined Cibolo and Dry Comal Creek basins occurred in 1992. With the exceptions of the Medina / Diversion Lake System and the Guadalupe Basin, it is apparent in Figure 3.2-1 that HDR recharge estimates generally exceed those prepared by the USGS. This is likely due to the selection of different partner areas for estimating potential runoff from the areas in which the Edwards formation outcrops. Again, the marked difference in Blanco River recharge estimates for 1992 (which was the wettest year

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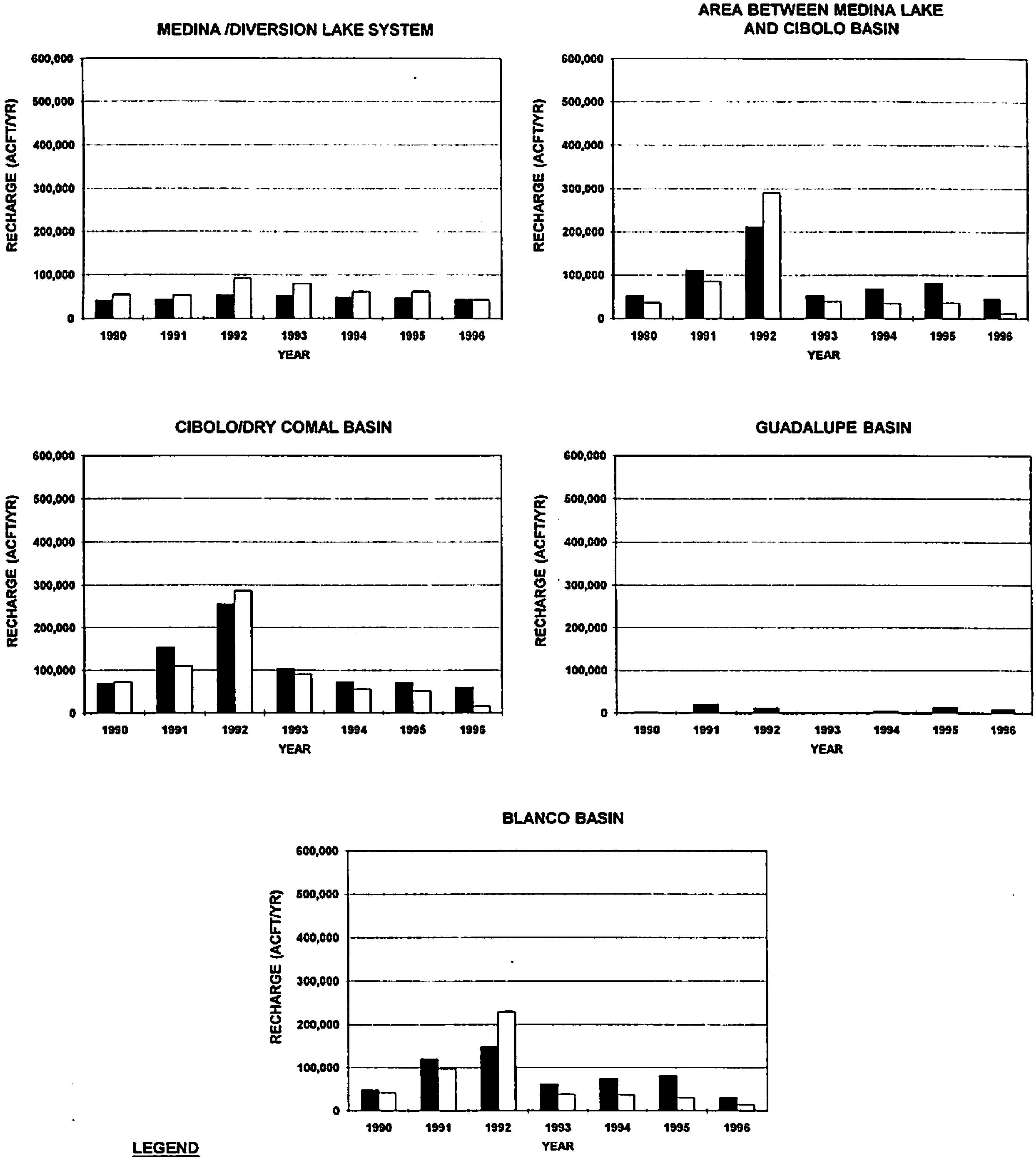
[3] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April, 1978.
[4] HDR, Op. Cit., September, 1993.



LEGEND

HDR

USGS

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ANNUAL EDWARDS AQUIFER RECHARGE COMPARISONS GSA RIVER BASIN

FIGURE 3.2-1

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during the 1990-96 period) is likely explained by the USGS application of a base flow curve in their computation procedure.

Both the USGS and HDR estimates of annual recharge in the Medina / Diversion Lake System were computed using curves relating reservoir storage (or water surface elevation) to recharge rate. Applicable curves, however, were obtained from different sources. The USGS uses curves originally derived by Lowry[5] and HDR uses curves developed by Espey Huston & Associates.[6] It is likely that both sets of curves will soon be superseded by information in an upcoming USGS report on the Medina Lake Project which is presently under internal review.[7]

Also of note in Figure 3.2-1 is that HDR reports small annual estimates of Edwards Aquifer recharge occurring in the intervening Guadalupe River watershed between Canyon Reservoir and New Braunfels. The USGS reports that "the Guadalupe River crosses the infiltration area of the Edwards Aquifer, but does not contribute recharge in significant quantities."[8] HDR estimates indicate that annual recharge occurring in this area was as great as 20,363 acft during the 1990-96 period, but represents less than 2 percent of the long-term (1934-96) average recharge for the Edwards Aquifer in the Nueces and Guadalupe - San Antonio River Basins.

3.3 General Comparisons

As indicated in Appendix A, Edwards Aquifer recharge averaged about 652,700 acft/yr during the 1934-96 historical period. This is comparable to the published USGS estimate of 668,600 acft/yr which is about 2.4 percent greater. Table 3.3-1 and Figure 3.3-1 provide convenient summaries for geographical comparison of long-term average Edwards Aquifer recharge estimates developed by HDR and the USGS. Substantial differences, both in terms of volume and percentage, are readily apparent in specific recharge basins as only the Cibolo / Dry Comal recharge basin shows estimates within 10 percent of one another. In order to understand the differences between the HDR and USGS recharge estimates, basic methodologies and

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[5] Lowry, R.L., "Recharge to the Edwards Ground Water Reservoir," San Antonio City Water Board, 1955.
[6] Espey, Huston & Associates, Inc., "Medina Lake Hydrology Study," Edwards Underground Water District, March, 1989.
[7] Lambert, R., Personal Communication, USGS, December, 1997.
[8] USGS, Op. Cit., April, 1978.

assumptions must be considered in some detail. The principal differences in recharge calculation methodology and procedures are associated with:

- Estimation of monthly potential runoff volumes for gaged and ungaged areas located atop the recharge zone (partner watershed, drainage area, areal precipitation, soil-cover complex, etc.);
- Base flow separation and accounting for storage in the Edwards Plateau Aquifer;
- Utilization of differing curves relating storage and recharge for the Medina / Diversion Lake System;
- Consideration of relatively small annual volumes of recharge for the Guadalupe River recharge basin; and
- Accounting for relatively small reported historical surface water diversions and treated effluent discharges.

For more detailed information on these differences, the reader is directed to referenced reports prepared by HDR and the USGS.

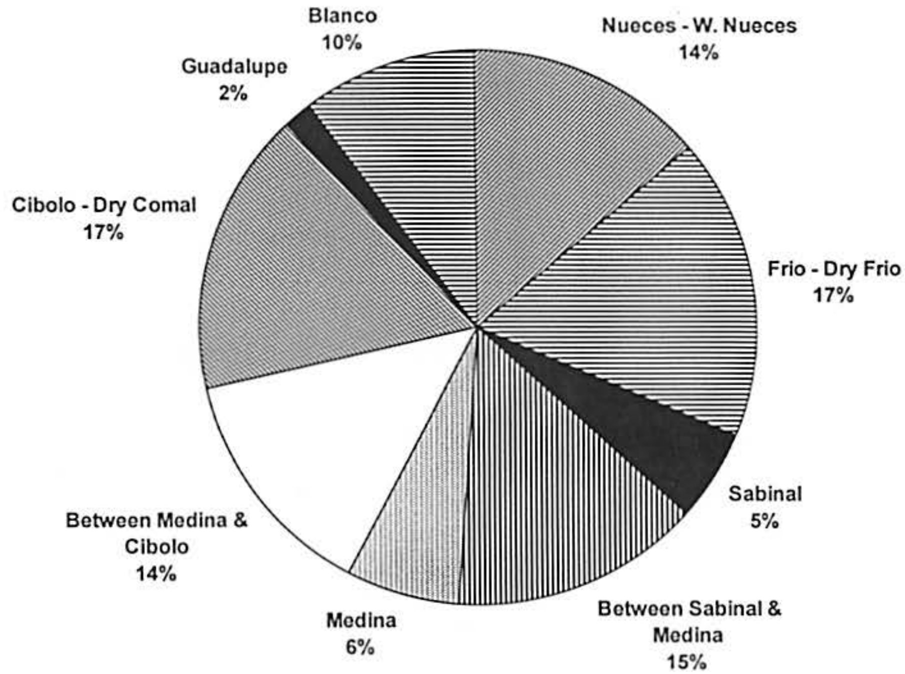
Table 3.3-1

Summary of Average Historical Edwards Aquifer Recharge by Basin (1934-96)

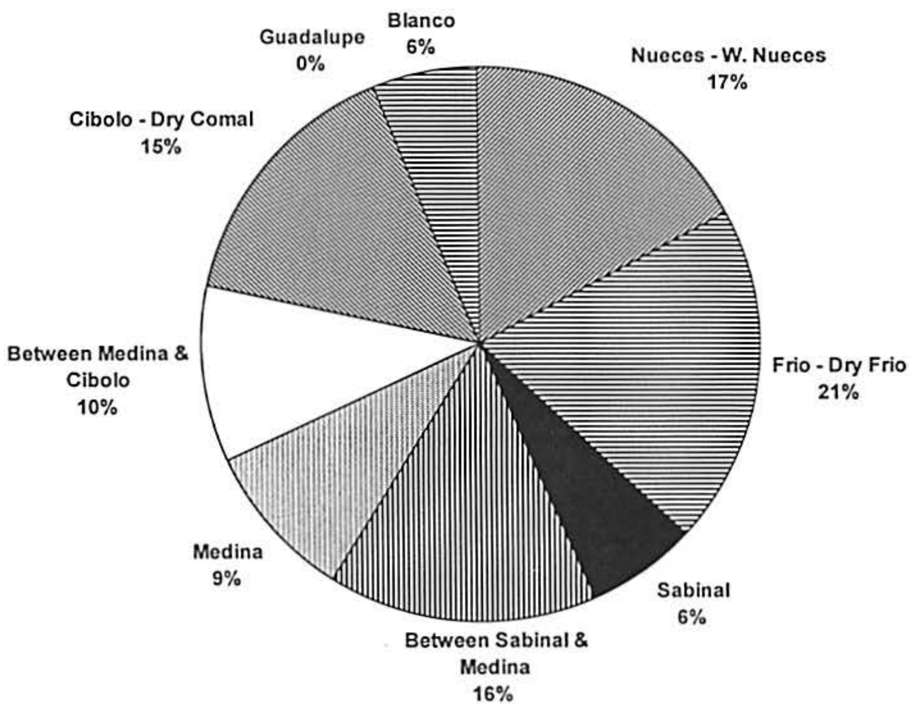
River Basin	Recharge Basin	HDR Recharge Estimate (Acft/Yr)	USGS Recharge Estimate (Acft/Yr)	Difference (Acft/Yr)	Percent Difference
	1. Nueces - W. Nueces	90,555	115,600	25,045	27.7%
	2. Frio - Dry Frio	114,824	131,900	17,076	14.9%
	3. Sabinal	33,201	41,400	8,199	24.7%
	4. Between Sabinal & Medina	95,818	105,500	9,682	10.1%
Nueces	SUBTOTAL	334,398	394,400	60,002	17.9%
	5. Medina	42,393	61,000	18,607	43.9%
	6. Between Medina & Cibolo	88,289	68,600	-19,689	-22.3%
San	7. Cibolo - Dry Comal	110,307	103,300	-7,007	-6.4%
Antonio	SUBTOTAL	240,989	232,900	-8,089	-3.4%
	8. Guadalupe	10,997	0	-10,997	-100.0%
	9. Blanco	66,322	41,300	-25,022	-37.7%
Guadalupe	SUBTOTAL	77,319	41,300	-36,019	-46.6%
	TOTAL	652,706	668,600	15,894	2.4%

Figure 3.3-2 provides two comparisons of HDR and USGS recharge estimates on a year by year basis for the entire 1934-96 historical period. Note that Edwards Aquifer recharge in 1992 was the greatest during the historical period (based on either HDR or USGS estimates) and

HDR RECHARGE ESTIMATES
(652,706 ACFT/YR)



USGS RECHARGE ESTIMATES
(668,600 ACFT/YR)



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GEOGRAPHICAL COMPARISON OF EDWARDS AQUIFER RECHARGE BY RECHARGE BASIN

HDR

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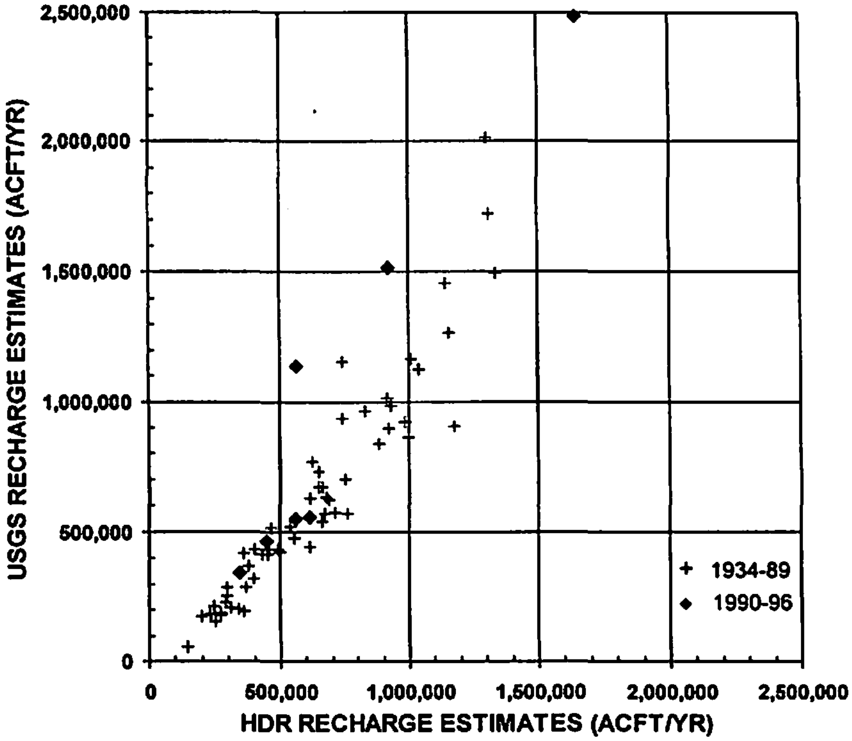
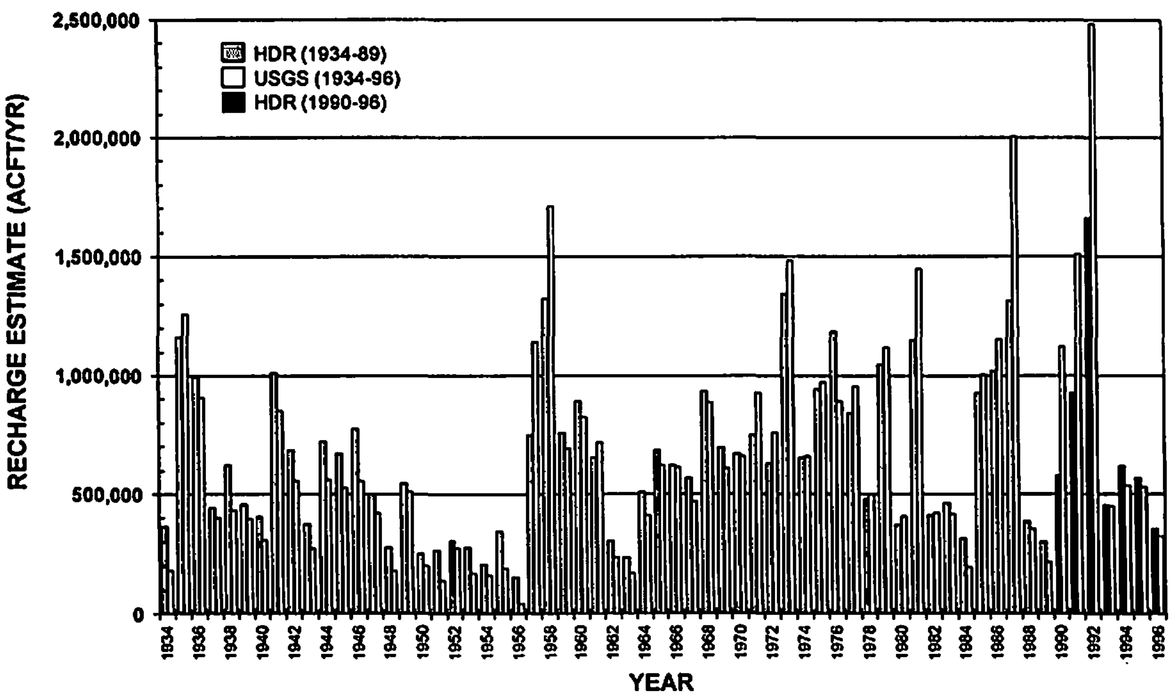
FIGURE 3.3-1





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LONG TERM EDWARDS AQUIFER RECHARGE COMPARISONS

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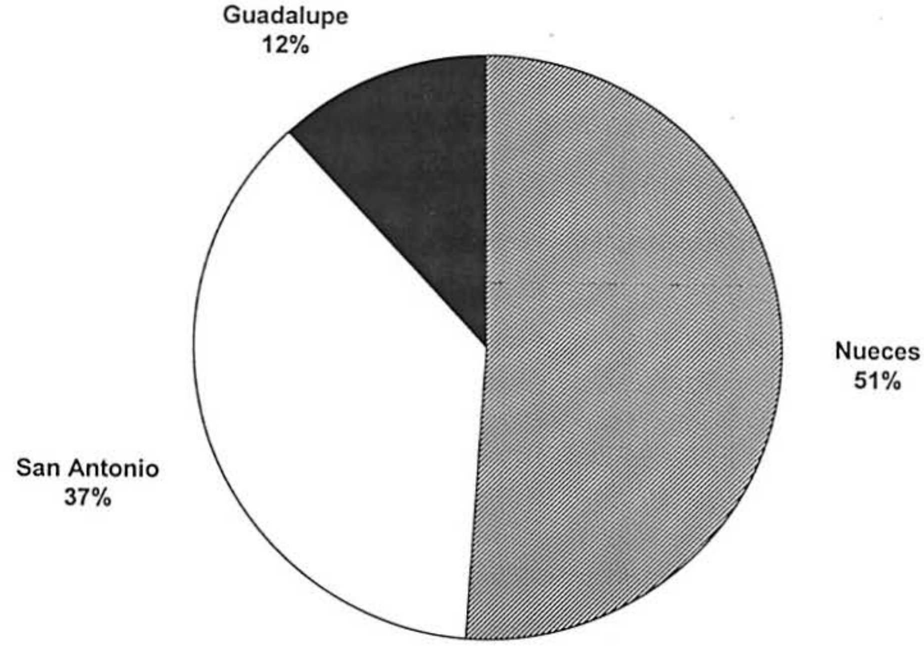
FIGURE 3.3-2

exceeded the next highest year by almost 20 percent. As is apparent in this figure, USGS recharge estimates are substantially greater than HDR estimates in the wettest years and somewhat less than HDR estimates in the driest years.

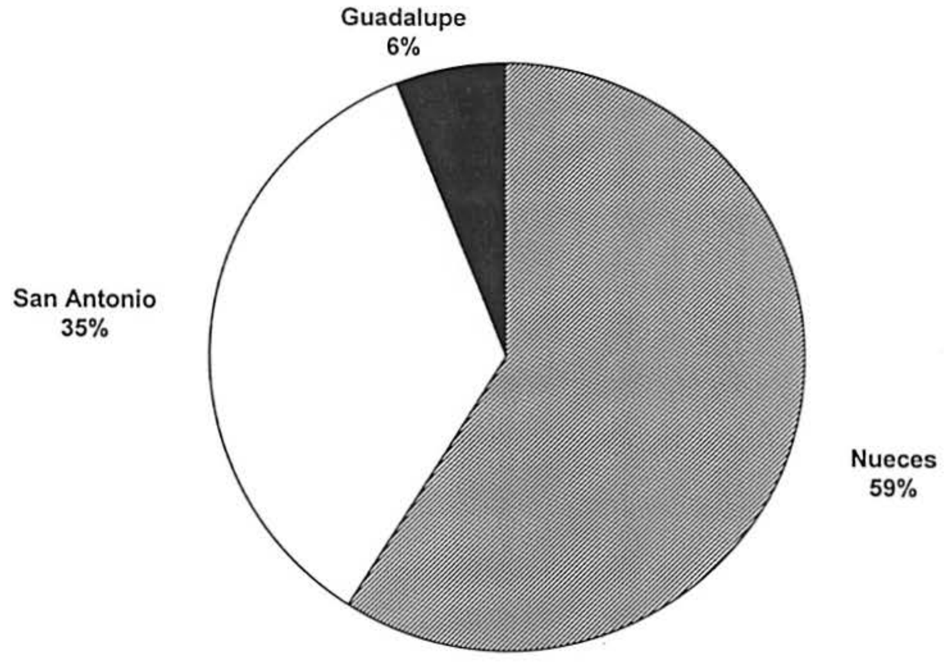
A comparison of the geographical distribution of long-term average Edwards Aquifer recharge on a river basin scale is presented in Figure 3.3-3. Clearly, USGS estimates are greater in the Nueces River Basin and substantially less in the Guadalupe River Basin. This difference in geographical recharge distribution is quite significant with respect to both calibration and application of Edwards Aquifer models. For example, complete reliance on USGS recharge estimates could result in overestimation of aquifer storage in the western counties and underestimation of reductions in well levels in San Antonio and springflows in Comal and Hays County. Similarly, complete reliance on USGS recharge estimates could result in overestimation of the effects of aquifer-wide pumpage on San Marcos Springs discharge due to underestimation locally occurring recharge in Hays County. Preliminary comparisons[9] indicate that the GWSIM4 model (originally calibrated using USGS recharge estimates) more accurately simulates historical springflows and Bexar County Monitoring Well levels when using HDR recharge estimates.

[9] HDR, Letter to Rick Illgner (EUWD), February, 28, 1994.

HDR RECHARGE ESTIMATES
(652,706 ACFT/YR)



USGS RECHARGE ESTIMATES
(668,600 ACFT/YR)



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GEOGRAPHICAL COMPARISON OF EDWARDS AQUIFER RECHARGE BY RIVER BASIN

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FIGURE 3.3-3

4.0 RECOMMENDATIONS

The hydrologic extremes experienced during the 1990-96 historical period serve to reemphasize the importance of hydrologic data collection and periodic reassessment of methodologies applied in estimation of Edwards Aquifer recharge. The following are several recommendations regarding opportunities for improvement of recharge estimates:

- Data collection efforts implemented through the EAA precipitation and streamflow gaging network should be published on an annual basis as this data can contribute significantly to the accuracy of areal precipitation, potential runoff, and recharge estimates for all areas over the Edwards Aquifer recharge zone.
- Results of the Medina Lake Project when completed by BMA, BCA, and the USGS should be used to revise recharge relationships presently used for the Medina / Diversion Lake System.
- Results of a series of streamflow measurements on the Guadalupe River between Canyon Reservoir and New Braunfels conducted by the EAA, TWDB, and Guadalupe-Blanco River Authority should be analyzed and published, and recharge computation procedures revised accordingly.
- USGS records should be researched to determine if estimates of surface runoff for the portion of Upper San Marcos watershed above the springflow/streamflow gaging station located on the San Marcos River (#08170000) can be developed.
- Potential linkage of the EAA precipitation gaging network to advanced radar systems capable of measuring and recording the spatial distribution of precipitation intensity during storm events should be considered to improve estimates of areal precipitation.
- An improved, unified methodology for recharge calculation incorporating the best features of HDR and USGS procedures should be developed considering appropriate information from other studies and especially the EAA's ongoing data collection efforts.

Development of the best possible recharge computation procedures and, in turn, the best estimates of historical recharge are logical prerequisites for calibration and application of the most accurate aquifer model(s) possible. Ultimately, the best practicable Edwards Aquifer model must be developed to provide a sound technical basis for regulatory applications by both the EAA and TNRCC. Such a model will also prove invaluable in the technical evaluation of potential water supply plans involving conjunctive water supply management for the San Antonio region.

APPENDIX A
HISTORICAL EDWARDS AQUIFER RECHARGE ESTIMATES

YEAR	NUECES RIVER AND WEST NUECES RIVER RECHARGE (ACFT)	FRIO RIVER AND DRY FRIO RIVER RECHARGE (ACFT)	SABINAL RIVER RECHARGE (ACFT)	SECO CREEK RECHARGE (ACFT)	HONDO CREEK RECHARGE (ACFT)	RIVER RGE 'T)	BLANCO RIVER PARTNER AREA YORK, SINK & PURGATORY CREEK RECHARGE (ACFT)	BLANCO RIVER AND PARTNER AREA TOTAL RECHARGE (ACFT)	NUECES RIVER BASIN TOTAL RECHARGE (ACFT)	GUADALUPE SAN ANTONIO RIVER BASIN TOTAL RECHARGE (ACFT)	HDR TOTAL RECHARGE (ACFT)
1934	32889	34733	9383	6433	91	29549	45199	74748	112757	254319	367076
1935	132831	321509	70191	112557	861	22676	25559	48234	821230	344188	1165418
1936	209504	168722	48431	68287	452	22058	29587	51645	591367	401951	993317
1937	40180	72612	21505	14152	179	21386	20845	42231	187839	255091	442931
1938	65562	65301	17441	11345	179	30418	49773	80191	201744	420922	622666
1939	219904	70809	16369	11545	155	12887	3868	16755	349833	110170	460003
1940	71156	66029	18404	11474	174	22401	21203	43604	205687	201891	407578
1941	102464	143376	44657	44741	456	43520	89837	133357	440104	569599	1009703
1942	79296	85483	26855	16652	254	35015	51894	86909	262625	420630	683255
1943	53958	45464	14284	8393	117	20022	15956	35978	150236	226943	377179
1944	96031	103684	22108	17417	218	33596	59580	93176	281724	438546	720269
1945	58175	96568	27181	23698	243	29689	45012	74701	259785	410340	670124
1946	105067	78828	22448	13634	154	35009	58761	93770	262234	508917	771151
1947	100972	81214	19759	13217	157	27722	39035	66757	247002	255390	502392
1948	55926	50832	12338	5392	33	16822	10592	27414	143631	135912	279543
1949	116471	111923	28351	23123	251	18319	12904	31223	340768	207032	547800
1950	59750	40605	14007	7994	100	15640	8853	24493	144837	107868	252706
1951	57189	35386	6326	6016	73	16051	19671	35722	138366	122515	260881
1952	30359	27428	9703	5547	80	17489	20863	38352	95686	205928	301615
1953	28556	30446	4619	7331	128	25585	31226	56811	99831	181026	280857
1954	43278	27478	4017	4110	43	14676	12185	26862	85996	120453	208449
1955	205474	30774	3208	1544	36	15159	17475	32634	251170	94826	345996
1956	25319	9345	4224	1451	56	12224	10106	22330	58716	94666	153383
1957	104250	92879	22490	36832	395	45215	47132	92347	345221	402894	748115
1958	199766	255735	70117	90232	681	29650	56265	85915	754190	571265	1325455
1959	104504	172540	51863	30689	305	37040	52205	89245	431239	327481	758720
1960	95578	133568	60338	36273	411	50778	58381	109159	408007	481750	889756
1961	123931	163843	52613	33361	352	12750	11017	23767	431577	223794	655370
1962	57671	53458	5202	3378	37	19538	20465	40003	130174	175528	305702
1963	47126	38198	6559	2060	25	17194	17336	34530	99173	139874	239047
1964	134656	67406	19902	24441	193	21413	19453	40866	297884	210076	507960
1965	114710	90686	44792	26648	323	33615	48391	82006	346806	337357	686163
1966	123092	100837	33251	27216	257	33285	42767	76052	334719	287181	621900
1967	82245	139032	39003	31879	197	17911	15798	33709	336115	228776	564892
1968	95065	183488	75500	78061	628	22694	37478	60172	547428	385067	932495
1969	120252	116967	35794	23247	342	27589	38011	65600	370617	323171	693788
1970	77417	124183	33424	16833	318	15243	45530	60772	312215	357904	670119
1971	167028	178302	32839	43109	297	16740	19523	36263	502413	245762	748175
1972	62963	126817	44298	52925	385	24779	26028	50807	362621	268664	631284
1973	146650	210451	56717	91223	894	43888	84078	127966	683221	662785	1346006
1974	45291	142177	41640	23890	315	28982	46191	75173	312607	342715	655321
1975	68271	127406	43110	40778	651	53952	86324	140276	391157	551648	942805
1976	123277	250626	65417	50701	684	40947	63168	104115	623298	562925	1186223
1977	18157	180811	60106	36184	553	37082	54249	91331	386873	452410	839283
1978	63320	80599	37764	22716	237	23075	17529	40604	259370	217532	476902
1979	87809	152844	52182	53886	733	40487	65294	105781	481572	566936	1048508
1980	52312	68291	23481	5980	114	21489	17504	38993	173833	196103	369935
1981	99236	236963	79443	77455	732	39114	92668	131782	631763	518927	1150689
1982	40941	100673	22684	13628	121	21382	16383	37765	202398	210570	412969
1983	91758	80656	26657	8909	172	27578	33379	60957	250401	215428	465829
1984	55405	46221	16221	11499	81	22407	13812	36219	144330	172325	316855
1985	91366	172152	55982	58714	61	35714	71924	107638	494970	431495	926464
1986	96000	134742	46738	59598	44	33393	58844	92237	422239	595873	1018112
1987	91216	288401	77781	109760	85	28619	76824	105443	752261	562377	1314638
1988	52841	97972	16541	4069	8	25282	22883	48165	186366	201385	387751
1989	45222	49915	8282	3330	5	26274	23466	49740	117262	180276	297537
1990	129509	129833	35504	32768	24	25306	22865	48170	364276	210607	574882
1991	125575	153580	46263	63194	50	35618	83581	119199	484905	445326	930230
1992	165437	296510	85215	168236	136	43263	105703	148965	979574	681594	1661168
1993	24385	75620	28933	24016	17	27525	34173	61698	185842	269106	454948
1994	135924	144347	26385	10237	14	36648	38902	75550	349562	270700	620262
1995	73991	108342	33694	21556	20	31613	49373	80987	274629	293550	620262
1996	80489	68299	11107	4173	1	16889	13534	30422	168775	185169	353944
AVG	90555	114824	33201	31615	31	27458	38864	66322	334398	318308	652706
MIN	18157	9345	3206	1451	1	12224	3868	16092	58716	94666	153383
MAX	219904	321509	85215	168236	136	53952	105703	159655	979574	681594	1661168

HISTORICAL EDWARDS AQUIFER RECHARGE ESTIMATES

YEAR	NUECES RIVER AND WEST NUECES RIVER RECHARGE (ACFT)	FRIO RIVER AND DRY FRIO RIVER RECHARGE (ACFT)	SABINAL RIVER RECHARGE (ACFT)	SECO CREEK RECHARGE (ACFT)	HONDO CREEK RECHARGE (ACFT)	VERDE & ELM CREEK RECHARGE (ACFT)	AREA BETWEEN SABINAL RIVER AND MEDINA RIVER RECHARGE (ACFT)	MEDINA LAKE AND DIVERSION LAKE RECHARGE (ACFT)	AREA BETWEEN MEDINA LAKE AND SALADO CREEK ON RECHARGE ZONE (ACFT)	AREA BETWEEN MEDINA LAKE AND SALADO CREEK ABOVE RECHARGE ZONE (ACFT)	SAN GERONIMO DAM RECHARGE (ACFT)	SALADO CREEK RECHARGE (ACFT)	AREA BETWEEN MEDINA LAKE AND CIBOLO CREEK TOTAL RECHARGE (ACFT)	CIBOLO CREEK RECHARGE (ACFT)	DRY COMAL CREEK RECHARGE (ACFT)	CIBOLO CREEK AND DRY COMAL CREEK TOTAL RECHARGE (ACFT)	ESTIMATED GUADALUPE RIVER RECHARGE (ACFT)	BLANCO RIVER RECHARGE (ACFT)	BLANCO RIVER PARTNER AREA YORK, SINK & PURGATORY CREEK RECHARGE (ACFT)	BLANCO RIVER AND PARTNER AREA TOTAL RECHARGE (ACFT)	NUECES RIVER BASIN TOTAL RECHARGE (ACFT)	GUADALUPE SAN ANTONIO RIVER BASIN TOTAL RECHARGE (ACFT)	HDR TOTAL RECHARGE (ACFT)
1934	32889	34733	9383	6433	9163	20156	35752	44497	6388	6867	0	33859	47114	16848	38790	55638	32323	29549	45199	74748	112757	254319	367076
1935	132831	321509	70191	112557	86159	97982	296698	47117	32974	31360	0	59167	123501	84493	34374	118867	6469	22676	25559	48234	821230	344188	1165418
1936	209504	168722	48431	68287	45294	51129	164710	53275	31785	30885	0	69011	131681	84026	44154	128180	37170	22058	29587	51645	591367	401951	993317
1937	40180	72612	21505	14152	17962	21428	53542	52235	15614	15384	0	38400	69398	46363	32606	78969	12258	21386	20845	42231	187839	255091	442931
1938	65582	65301	17441	11345	17908	24168	53420	48820	27304	26193	0	63425	116923	65812	78144	143956	31032	30418	49773	80191	201744	420922	622666
1939	219904	70609	16369	11545	15549	15657	42751	40604	4226	4663	0	9328	18217	11356	3971	15327	19266	12887	3868	16755	349833	110170	460003
1940	71156	66029	18404	11474	17418	21206	50098	30201	12906	12846	0	19909	45662	36522	19212	55734	26689	22401	21203	43604	205687	201891	407578
1941	102464	143376	44657	44741	45640	59226	149607	43076	45120	42664	0	83039	171023	102432	98172	200604	21540	43520	89837	133357	440104	569599	1009703
1942	79296	85483	26855	16652	25497	28841	70991	44469	29016	28037	0	63483	120536	66812	74746	141558	27158	35015	51894	86909	262625	420630	683255
1943	53958	45464	14284	8393	11707	16431	36531	42925	12957	13066	0	35990	62013	38514	35492	74006	12020	20022	15956	35978	150236	226943	377179
1944	96031	103684	22108	17417	21856	20627	59900	40824	33504	32174	0	81370	147049	87892	64032	151924	5573	33596	59580	93176	281724	438546	720269
1945	58175	96568	27181	23698	24346	29815	77860	42124	33414	31457	0	53454	118325	86502	71717	158219	16971	29689	45012	74701	259785	410340	670124
1946	105067	78828	22448	13634	15454	26802	55891	39602	30699	29752	0	90221	150672	107295	94639	201934	22940	35009	58761	93770	262234	508917	771151
1947	100972	81214	19759	13217	15794	16045	45056	38385	11061	11101	0	24219	46381	48102	39040	87142	16725	27722	39035	66757	247002	255390	502392
1948	55926	50832	12338	5392	3399	15744	24535	18890	10011	10265	0	15382	35658	18741	13704	32445	21505	16822	10592	27414	143631	135912	279543
1949	116471	111923	28351	23123	25142	35757	84022	30907	15862	15717	0	33401	64979	37414	31540	68954	10970	18319	12904	31223	340768	207032	547800
1950	59750	40605	14007	7994	10040	12442	30476	13274	7106	7454	0	17310	31870	21069	7626	28695	9537	15640	8853	24493	144837	107888	252706
1951	57189	35388	6326	8016	7324	24124	39465	10256	9726	10097	0	9778	29601	16856	13446	30302	16634	16051	19671	35722	138366	122515	260881
1952	30359	27428	9703	5547	8050	14600	28197	12922	21814	20868	0	17230	59912	70425	14477	84902	9841	17489	20863	38352	95686	205928	301615
1953	28556	30446	4619	7331	12891	15988	36210	18343	5536	5902	0	17215	28652	25078	33314	58392	17827	25585	31226	56811	99831	181026	280857
1954	43278	27478	4017	4110	4374	2739	11223	23430	4020	4178	0	18500	26698	9370	15717	25087	18376	14676	12185	26862	85996	120453	206449
1955	205474	30774	3206	1544	3627	6544	11715	10789	910	1148	0	6783	8839	2984	12193	15177	27389	15159	17475	32634	251170	94826	345996
1956	25319	9345	4224	1451	5692	12685	18828	11076	1104	1348	0	12244	14695	1683	17726	19409	27156	12224	10106	22330	58716	94666	153383
1957	104250	92879	22490	36832	39567	49204	125602	29316	32085	30416	0	58741	121242	99482	52531	152013	7977	45215	47132	92347	345221	402894	748115
1958	199766	255735	70117	90232	68194	70146	228572	51508	52854	49554	0	93127	195535	149136	82545	231681	6626	29650	56265	85915	754190	571265	1325455
1959	104504	172540	51863	30689	30588	41055	102332	52939	26241	25378	0	24574	76193	60568	40888	101456	7648	37040	52205	89245	431239	327481	758720
1960	95579	133568	60338	36273	41160	41089	118522	52554	36751	34909	0	56222	127882	121568	59948	181516	10639	50778	58381	109159	408007	481750	889756
1961	123931	163843	52613	33361	35205	22624	91190	52799	20296	19846	0	19753	59695	60595	21204	81799	5734	12750	11017	23767	431577	223794	655370
1962	57671	53458	5202	3378	3794	6671	13843	48709	6924	7265	0	22656	36845	15857	21759	37616	12355	19538	20465	40003	130174	175528	305702
1963	47128	38198	6559	2060	2543	2687	7290	41556	4900	5334	0	16879	27113	5242	23196	28438	8237	17194	17336	34530	99173	139874	239047
1964	134656	67406	19902	24441	19384	32095	75920	35347	16588	16659	0	22200	55448	46856	26452	73308	5107	21413	19453	40866	297884	210076	507960
1965	114710	90686	44792	26648	32312	39658	98618	40893	23555	22851	0	46493	92899	63800	57754	121554	0	33615	48391	82006	348806	337357	686163
1966	123092	100837	33251	27216	25714	24609	77539	41191	14853	14601	0	48408	77862	32628	54978	87606	4470	33285	42767	76052	334719	287181	621900
1967	82245	139032	39003	31879	19708	24248	75835	37456	13758	13891	0	37913	65562	40724	39636	80360	11690	17911	15798	33709	336115	228776	564892
1968	95065	183488	75500	78081	62831	52483	193375	46319	28920	29244	0	50765	108929	114126	55085	169211	436	22694	37478	60172	547428	385067	932495
1969	120252	116967	35794	23247	34233	40125	97605	46448	24813	31883	0	37075	93772	65919	43854	109773	7578	27589	38011	65600	370617	323171	693788
1970	77417	124183	33424	16833	31828	28530	77191	49115	25941	32348	0	34652	92941	92674	53411	146085	6991	15243	45530	60772	312215	357904	670119
1971	167028	178302	32839	43109	29702	51433	124244	48401	20526	18352	0	22081	60940	78457	19802	98259	1900	16740	19523	36263	502413	245762	748175
1972	62963	126817	44298	52925	38546	37071	128543	52951	12102	22671	0	27631	62404	67772	34090	101862	640	24779	26028	50807	362621	268664	631284
1973	146650	210451	56717	91223	89441	88739	269403	52974	57142	51776	0	117150	226068	127151	121146	248297	7479	43888	84078	127966	683221	662785	1346006
1974	45291	142177	41640	23890	31591	28018	83499	53005	13937	24472	0	30456	68875	80363	53837	134200	11481	28982	46191	75173	312607	342715	655321
1975	68271	127406	43110	40778	65172	46420	152370	53026	36706	51565	0	58566	146837	139624	69074	208698	2811	53952	86324	140276	391157	551648	942805
1976	123277	250626	65417	50701	68496	64781	183978	52628	40204	36837	0	102385	179426	123955	93529	217484	9272	40947	63168	104115	623268	562925	1186223
1977	18157	180811	60106	36184	55301	36313	127799	52908	29056	30241	0	72860	132158	108450	69564	176014	0	37082	54249	91331	386873	452410	839283
1978	63320	80599	37764	22716	23751	31220	77687	51880	10422	17181	0	25035	52638	31904	35328	67232	5178	23075	17529	40604	259370	217532	476902
1979	87609	152844	52182	53886	73367	61484	188737	53015	42277	33473	0	91955	167705	147184	90866	238050	2385	40487	65294	105781	481572	568936	1048508
1980	52312	68291	23481	5680	11429	12339	29749	50168	7619	12981	0	19210	39790	31629	32450	64079	3073	21489	17504	38993	173833	196103	369935
1981	99236	236963	79443	77455	73218	65448	216121	52361	40474	31177	1407	65963	139021	112245	82772	195017	746	39114	92668	131782	631763	518927	1150689
1982	40941	100673	22684	13628	12178	12294	38100	51718	8943	13222	91	30968	53224	36799	25869	62668	5195	21382	16383	37765	202398	210570	412969
1983	91758	80656	26657	8909	17222	25199	51330	48329	8347	14439	0	17450	40235	32516	29754	62270	3637	27578	33379	60957	250401	215428	465829
1984	55405	46221	16221	11499	8109	6875	26483	42320	9788	14808	0	28795	53390	27634	10932	38566	1830	22407	13812	36219	144330	172325	316655
1985	91366	172152	55982	58714	61388	55369	175470	44162	21945	29340	1098	81824	134207	72656	72140	144796	691	35714	71924	107638	494970	431495	926464
1986	96000	134742	46738	59598	44939	40222	144759	48552	50390	61814	963	92499	205685	148490	90147	238637	10781	33393	58844	92237	422239	595873	1018112
1987	91216	288401	77781	109760	85586	99518	294863	53217	41404	66330	1176	77509	186419	122444	86486	208930	8368	28619	76824	105443	752261	562377	1314638
1988	52841	97972	16541	4069	8924	6020	19012	50855	7907	12903	0	30243	51053	20795	27169	47964	3348	25282	22683	48165	186366	201385	387751
1989	45222	49915	8282	3330	5205	5308	13843	44998	4653	7242	0	30059	41954	13457	23491	36948	6635	26274	23466	49740	117262	180276	297537
1990	129509	129833	35504	32768	24530	12131	69429	41708	9943	15284	41	26359	51627	42373	25362	67735	1367	25306	22865	48170	364276	210607	574882
1991	125575	153580	46263	63194	50079	46214	159487	42601	27396	18926	1647	62535	110504	52983	99675	152658	20363	35618	83581	119199	484905	445326	930230
1992	165437	296510	85215	168236	136235	127942	432412	53197	51254	29787	2731	127208	210981	134714	120772	255486	12965	43263	105703	148965	979574	681594	1661168
1993	24385	75620	28933	24016	17807	15082	56905	51838	6266	26276	334	19728	52604	70837.	32329	102966	0	27525	34173	61698	185842	269106	454948
1994	135924	144347	26385	10237	14851	17818	42906	48875	10701	17365	0	40077	68143	35556	37069	72625	5507	36648	38902	75550	349562	270700	620262
1995	73991	108342	33694	21556	20052	16993	58602	47498	11721	17324	51	50997	80093	27324	43324	70648	14325	31613	49373	80987	274629	293550	568180
1996	80489	68299	11107	4173	1894	2814	8881	42397	13097	20324	0	11523	44944	54541	4871	59412	7993	16889	13534	30422	168775	185169	353944
AVG	90555	114824	33201	31615	31212	32991	95818	42393	21044	22598	151	44496	68289	63419	46888	110307	10997	27458	38884	66322	334398	318308	652706
MIN	18157	9345	3206	1451	1894	2687	7290	10256	910	1146	0	6783	8839	1683	3971	15177	0	12224	3868	16092	58716	94666	153383
MAX	219904	321509	85215	168236	136235	127942	432412	53275	57142	66330	2731	127208	226068	149136	121146	255486	37170	53952	105703	159655	979574	681594	1661168

Aquifer Simulations With Alternative Recharge Estimates

HDR

February 28, 1994

Mr. Rick Illgner
General Manager
Edwards Underground Water District
1615 N. St. Mary's
San Antonio, Texas 78212

Dear Mr. Illgner:

Pursuant to various discussions with you and members of your staff, we have enclosed a series of graphs which compare the springflows and aquifer levels from the Texas Water Development Board Edwards Aquifer model to historic observations using the USGS recharge estimates and the HDR recharge estimates. The plots compare the results of the TWDB model at Comal Springs, San Marcos Springs, and at the Bexar County Monitoring Well (J-17). This data was provided to us by the TWDB during our continuing discussions with the USGS and the TWDB regarding technical issues related to Edwards Aquifer recharge. It is important to note that the TWDB model has only been calibrated to the USGS recharge estimates. The calibration was performed with the emphasis on matching the drought conditions using the USGS recharge estimates. HDR recharge estimates were input into the model in place of the USGS recharge estimates, however, no recalibration of the model was performed when the HDR recharge estimates were simulated.

Figure 1, Figure 2, and Figure 3 show time traces of Comal Springs discharge, San Marcos Springs discharge, and Bexar County Monitoring Well (J-17) level, respectively. These three plots show the simulated records from the TWDB model using the USGS and HDR recharge estimates in comparison with historical observations for the drought period (1947-59) and for a more recent period (1978-89). Figure 4, Figure 5, and Figure 6 present a comparison of the simulated records using the USGS recharge estimates and HDR recharge estimates versus the historical observations at the three locations. If the results of the simulations exactly matched the historical observations, the data points would fall on the line shown on the individual graphs. Some general comments on each of figures are as follows:

- **Figure 1 - Comal Springs Time Trace**

  Figure 1 shows the time traces of simulated and observed springflow for the 1947-59 period and 1978-89 period. In general, the HDR recharge estimates provided a closer approximation of historical springflows during the 1947-59 period than did the USGS recharge estimates. Using the HDR recharge estimates, the model showed that

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Comal Springs did not cease to flow in 1956 as occurred historically. This may be due to the fact that the TWDB model was not recalibrated using the HDR recharge estimates. A closer approximation of historical springflow using the HDR estimates was especially evident for the wet period following 1956. For the more recent period of 1978-89, the HDR recharge estimates provided a more accurate simulation of historical springflows for the higher flow periods, however when historical flows were in the range of 200 cfs to 300 cfs, the USGS recharge estimates appeared to produce improved results.

- **Figure 2 - San Marcos Springs Time Trace**

Figure 2 shows the time traces of simulated and observed springflow for the 1947-59 period and 1978-89 period. San Marcos Springs showed the most variability in the comparisons of historical to simulated springflows using the HDR recharge estimates and USGS recharge estimates. For both periods, the HDR recharge estimates simulated historical springflows more accurately than did the USGS recharge estimates. The TWDB model tends to support the belief that springflow at San Marcos Springs is heavily influenced by the recharge that occurs locally (i.e. Blanco River, Upper San Marcos River, Guadalupe River).

- **Figure 3 - Bexar County Monitoring Well (J-17) Time Trace**

Figure 3 shows the time traces for the 1947-59 period and 1978-89 period for the well level at the Bexar County Monitoring Well J-17. The TWDB model results showed that HDR recharge estimates simulated historical levels more accurately than did the USGS recharge estimates during the depths of the drought (1952-56) and performed better overall for the 1947-59 period. For the 1978-89 period, both sets of recharge estimates produced simulated levels that are lower than the historical levels, although the USGS recharge estimates did tend to produce slightly better results during this period than the HDR recharge estimates.

- **Figure 4 - Comal Springs**

Figure 4 shows the historical flows compared to the simulated flows obtained using the HDR and USGS recharge estimates for the periods of 1947-59 and 1978-89 for Comal Springs. As shown in the Figure 1 time trace, the HDR recharge estimates provided a better match throughout the range of flows, although simulated springflows did not cease in 1956. For the same period, the USGS recharge estimates were consistently lower than historical conditions, except for occasionally high values. For the 1978-89 period, the HDR recharge estimates show a questionable fit in the 200 cfs to 300 cfs range. For the 1978-89 period, the USGS recharge estimates show a somewhat better fit when springflow is below 300 cfs. When historical flows exceeded 300 cfs, the USGS recharge estimates resulted in simulated flows that were significantly higher than historical flows. The HDR recharge estimates tended to provide better results for flow conditions above 300 cfs, although simulated flows were slightly higher than historical flows.

- **Figure 5 - San Marcos Springs**

  Figure 5 shows the historical flows compared to the simulated flows obtained using HDR and USGS recharge estimates for the periods of 1947-59 and 1978-89 for San Marcos Springs. For the 1947-59 period, the HDR recharge estimates produced a better long-term volume match to historical flows than did those produced using the USGS estimates. The HDR recharge estimates did produce more variation in simulated flows than the USGS recharge estimates. Both sets of recharge estimates produced simulated flows which indicate a questionable calibration of the TWDB model. For the higher flow conditions, both sets of recharge estimates tended to simulate springflows which were less than historical flows. Similar observations are noted for the 1978-89 period.

- **Figure 6 - Bexar County Monitoring Well (J-17)**

  Figure 6 shows the historical well levels compared to the simulated levels obtained using the HDR and USGS recharge estimates for the periods of 1947-59 and 1978-89 for the Bexar County Monitoring Well (J-17). For the 1947-59 period, the HDR recharge estimates provided results which more accurately simulated historical levels than did those produced using the USGS recharge estimates. The HDR recharge estimates tended to closely match historical levels below 650 ft-msl. However, for higher well levels, the levels calculated by the TWDB model using the HDR estimates tended to be lower than historical levels. For the 1947-59 period, the USGS recharge estimates produced levels which were consistently lower than historical levels throughout the range of well levels. For the 1978-89 period, both sets of recharge estimates produced levels which were consistently lower than historical levels, although the USGS recharge estimates were slightly better. The results for the 1947-59 period and 1978-89 period raise questions as to the adequate calibration of the TWDB model for aquifer levels above 650 ft-msl. As stated previously, the TWDB model was calibrated to most accurately simulate low aquifer levels and springflows.

This letter is provided with the intent of providing a brief, general assessment of the ability of the TWDB Edwards Aquifer model to simulate key springflow and well levels using alternative recharge estimates developed by HDR and the USGS Overall, the TWDB Edwards Aquifer model seemed to more accurately simulate historical observations using the HDR recharge estimates. The TWDB model was calibrated to drought conditions, when the aquifer levels and springflows were low, using the USGS recharge estimates. It is possible that, if the model were recalibrated using the HDR recharge estimates, more accurate results could be obtained. Both sets of recharge estimates suggest that the TWDB model needs to be better calibrated in the San Marcos Springs area and for mid-range to higher aquifer level conditions.

If you have any questions or comments, please contact any of us at your convenience.

Sincerely,

HDR Engineering, Inc.

for Kenneth L. Choffel, P.E.
Vice President

Samuel K. Vaugh, P.E.
Project Manager

Kelly J. Kaatz, P.E.
Project Engineer

cc: Steve Walthour, EUWD
Greg Rothe, G.E. Rothe Co.

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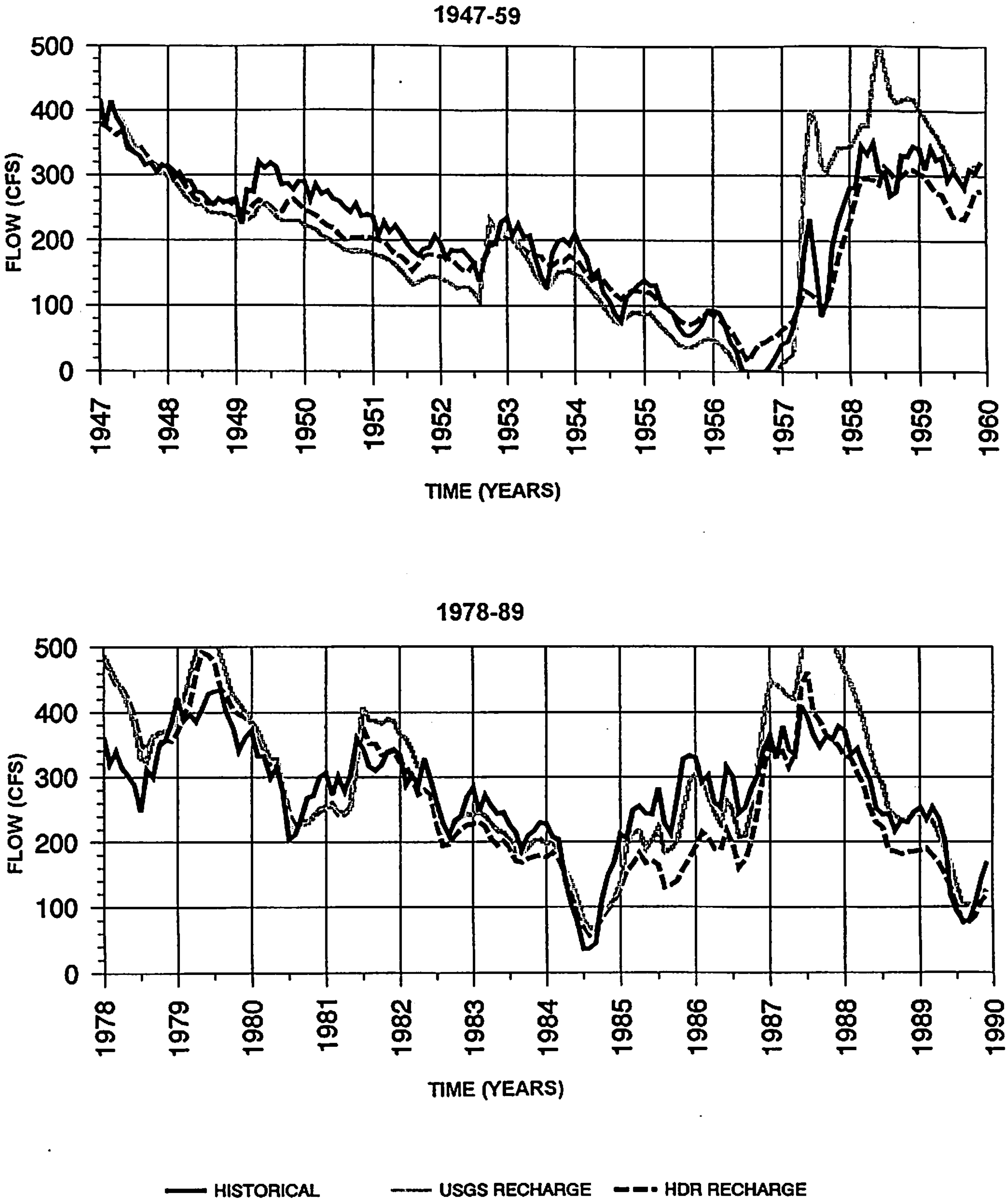
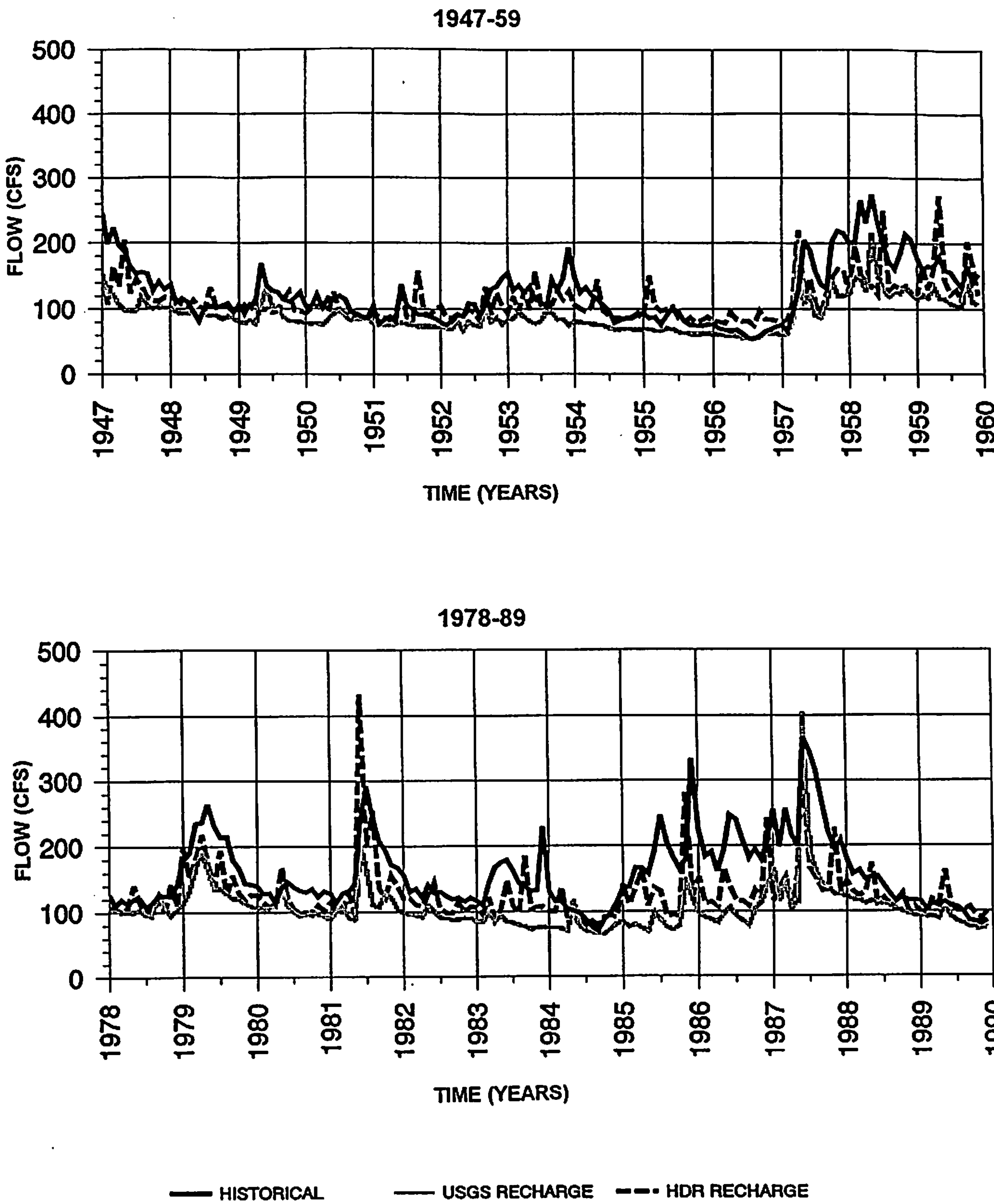


HDR Engineering, Inc.

HDR/USGS RECHARGE COMPARISON

COMAL SPRINGS

FIGURE 1



HDR

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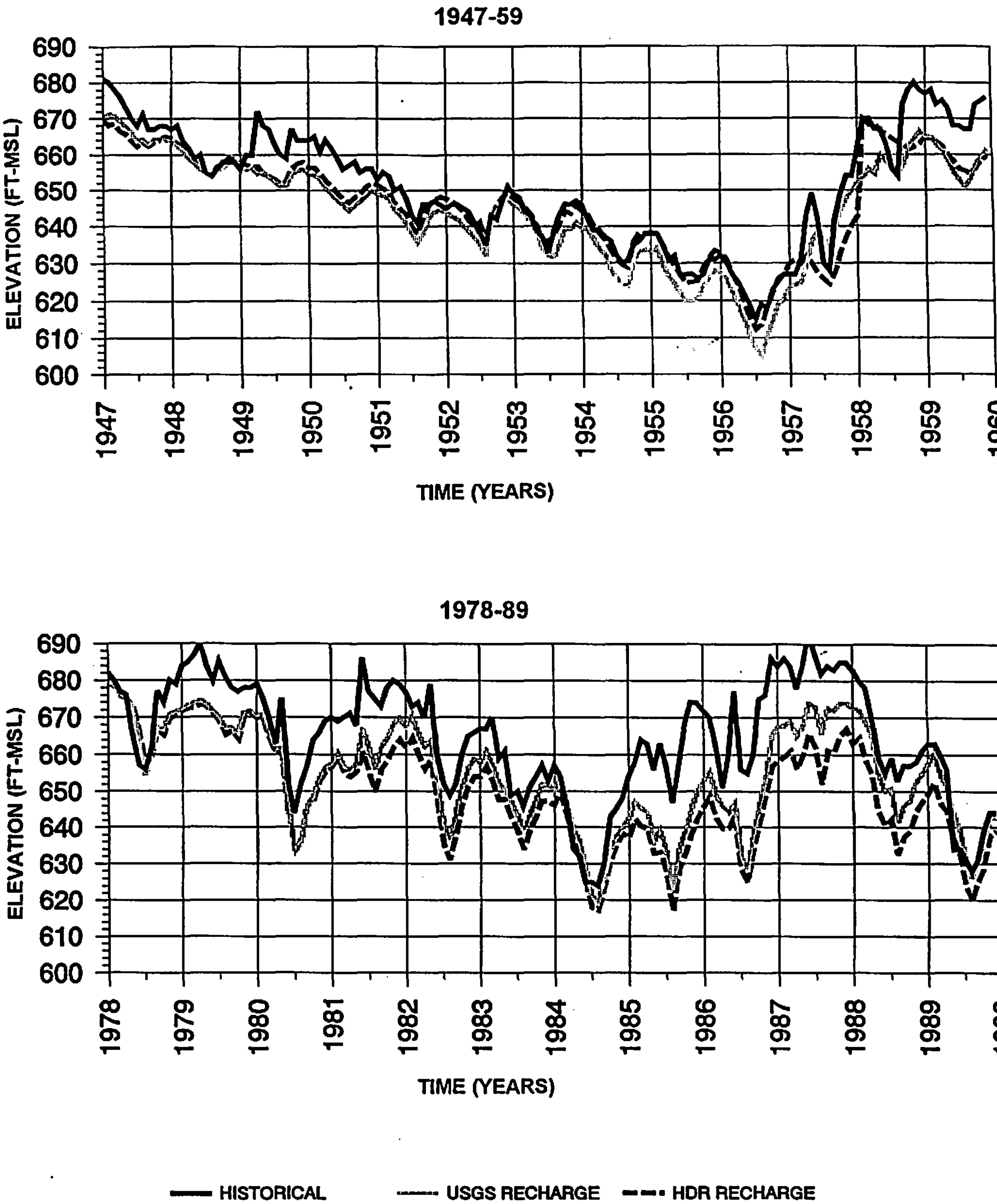
HDR/USGS RECHARGE COMPARISON

SAN MARCOS SPRINGS

FIGURE 2



HDR

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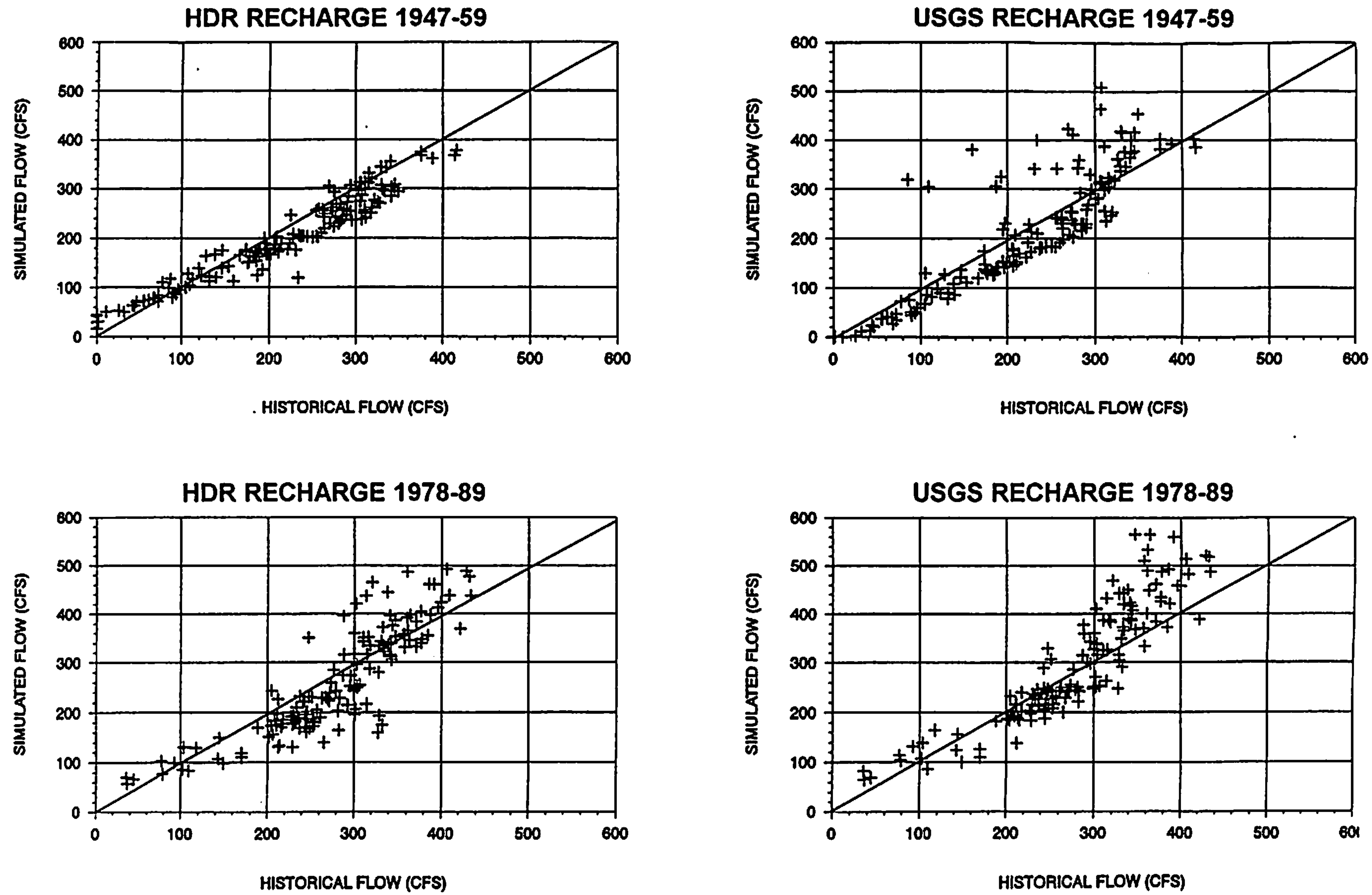
HDR/USGS RECHARGE COMPARISON

BEXAR CO. MONITORING WELL (J-17)

FIGURE 3



HDR

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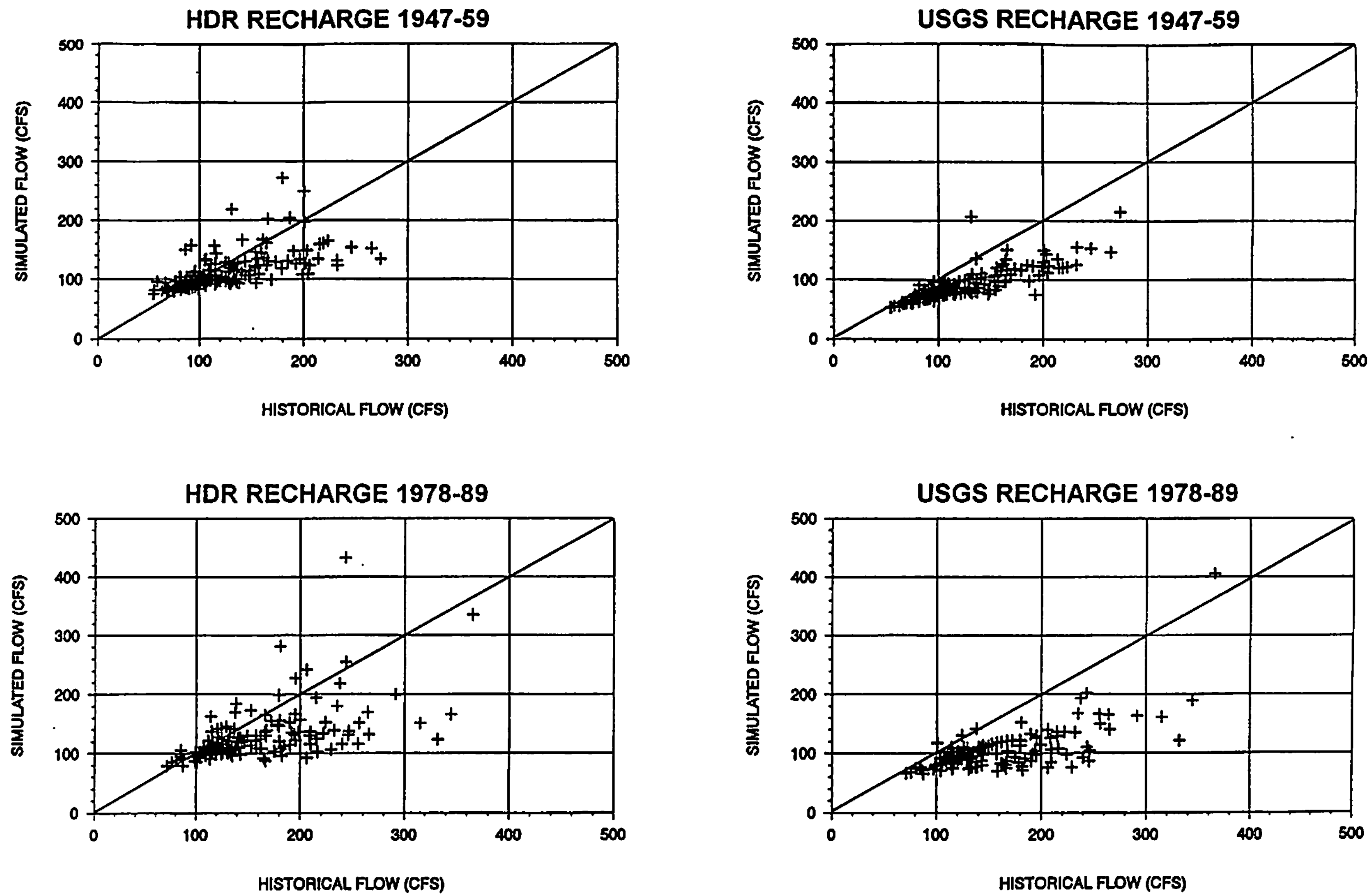
HDR/USGS RECHARGE COMPARISON

COMAL SPRINGS

FIGURE 4



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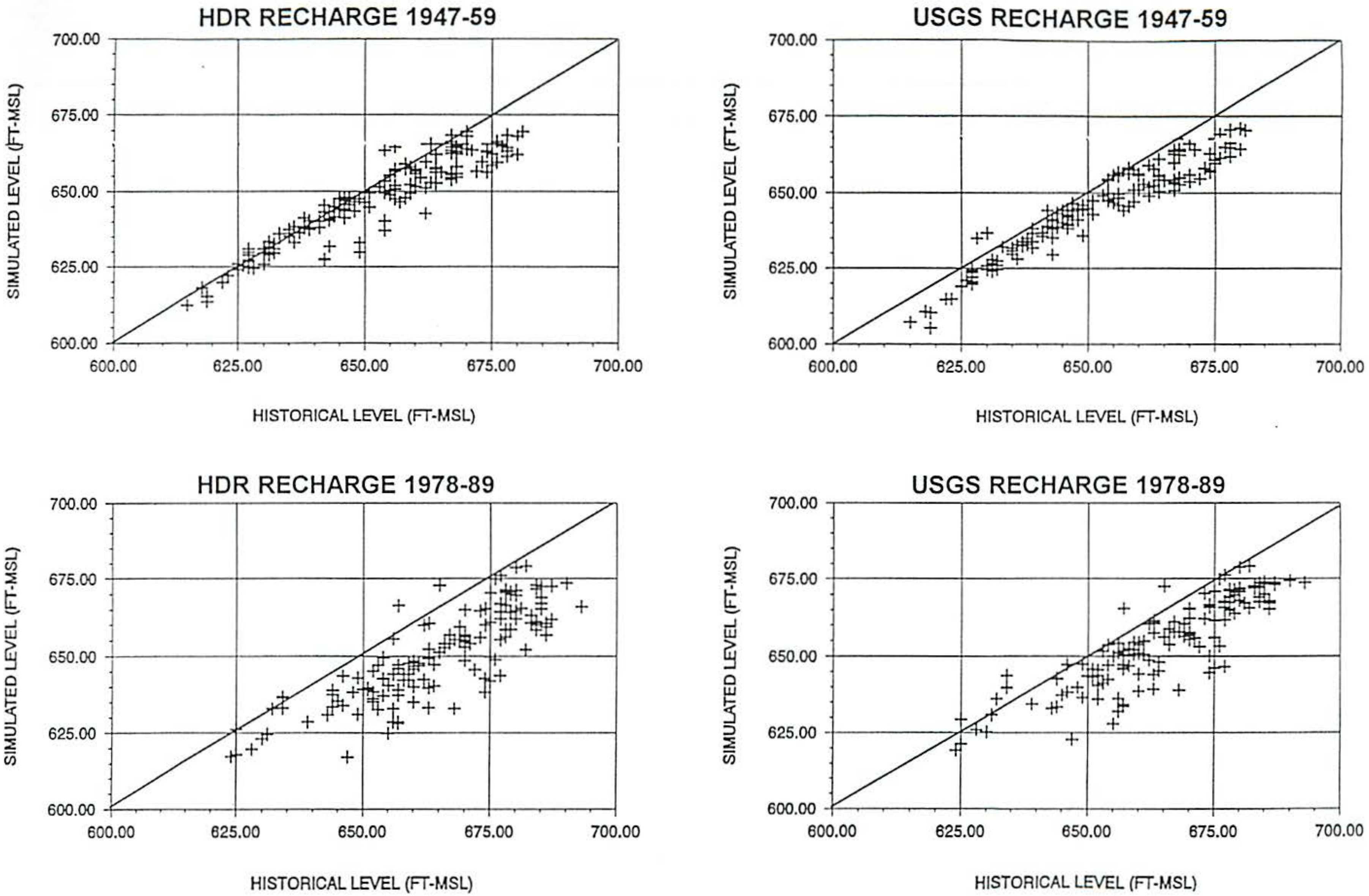
HDR/USGS RECHARGE COMPARISON

SAN MARCOS SPRINGS

FIGURE 5



HDR Engineering, Inc.

HDR/USGS RECHARGE COMPARISON

BEXAR CO. MONITORING WELL (J-17)

FIGURE 6

Some Key Issues For Improved Edwards Aquifer Modeling

Selected Key Issues and Short-Term Objectives for Recalibration of the TWDB Edwards Aquifer Model (GWSIM4)

HDR Engineering, Inc. and LBG-Guyton Associates
February 14, 1995

Following is a brief summary list of selected key issues and short-term objectives for recalibration and improvement of the Texas Water Development Board (TWDB) Edwards Aquifer Model (GWSIM4). Items comprising this list are either based on our own observations and experience or on our understanding of the observations and experience of others actively involved with the development and application of Edwards Aquifer models. It is recognized that simulation of the physical processes occurring in the Edwards Aquifer is an evolving science, hence both short-term and long-term objectives should be considered for the collection of basic data and development of model capabilities. The following list focuses on relatively short-term objectives which we believe can be reasonably achieved using data presently available and the existing model format.

Model Recalibration

1. Modify recharge estimates to reflect results of recent aquifer divide study which indicates that recharge in the Onion Creek watershed contributes to the San Antonio portion of the Edwards Aquifer. This study was conducted by LBG-Guyton for the Edwards Underground Water District (EUWD) and is presently in draft form pending approval by EUWD staff and Board of Directors. Consideration of Onion Creek recharge could help resolve the fact that the GWSIM4 model significantly underestimates discharge from San Marcos Springs.

2. Estimates of historical recharge of the Edwards Aquifer have been developed for the 1934-89 period by both the U.S. Geological Survey (USGS) and by HDR in the course of studies performed for the EUWD and others. Although GWSIM4 was calibrated using USGS estimates of historical recharge, the TWDB has performed numerous simulations with GWSIM4 using both USGS and HDR/EUWD recharge estimates during the past several years. In late 1993, comparisons of GWSIM4 results using both sets of recharge estimates were made. When these results were compared to actual historical springflows and well levels, it was found that results based on HDR/EUWD recharge estimates more closely approximated observed values (See Table 1). This finding is significant in that, even without recalibration of the model, the HDR/EUWD recharge estimates produced more accurate results. Based on these comparisons and other considerations summarized in the following paragraph, all GWSIM4 simulations used in the Trans-Texas Water Program were performed using HDR/EUWD estimates of historical recharge. Therefore, we strongly recommend that HDR/EUWD estimates of historical Edwards Aquifer recharge (as modified in Item 1) be adopted for recalibration of GWSIM4.

Table 1 Comparison of GWSIM4 Results Using HDR/EUWD and USGS Recharge Estimates To Historical Springflows and Well Levels[1]				
	Recharge Estimates with GWSIM4 Results Most Closely Approximating Historical Springflow or Well Level[2]			
Location	High Range	Middle Range	Low Range	Lowest Range
Comal Springs	HDR/EUWD	HDR/EUWD	HDR/EUWD	USGS
San Marcos Springs	HDR/EUWD	HDR/EUWD	HDR/EUWD	USGS
J-17	HDR/EUWD	HDR/EUWD	HDR/EUWD	HDR/EUWD

[1] Comparison based on 1947-59 calibration period selected by TWDB.
[2] TWDB GWSIM4 model has been calibrated only to USGS recharge estimates.

HDR/EUWD recharge estimates use updated drainage areas in the Nueces River Basin, account for historical diversions, account for differences in soil cover complex between areas upstream of and directly over the outcrop, and use improved estimates of areal precipitation. HDR/EUWD estimates of historical recharge account for recharge in the Guadalupe River Basin above New Braufels and are significantly greater than U.S. Geological Survey (USGS) estimates in the Upper San Marcos River watershed. Application of the GWSIM4 model using HDR/EUWD recharge significantly improves simulation of discharge from San Marcos Springs. Although HDR/EUWD recharge estimates are by no means perfect, we feel that they represent significant improvement over USGS estimates (especially in the eastern portions of the recharge zone) and should be used until additional information becomes available from the EUWD gaging network, USGS/BMA Medina Lake studies, USGS/GBRA Guadalupe River studies, etc.

3. Consider calibration to a variety of monitoring well levels and springs, rather than focusing on the period of zero flow at Comal Springs. Although it correctly simulates the duration of flow cessation at Comal Springs, the existing GWSIM4 model underestimates both Comal Springs discharge and J-17 levels throughout the remainder of the 1950's drought. Simulation of J-17 levels for the 1952-56 period is improved using HDR/EUWD, rather than USGS, recharge estimates.

4. Consider calibration to the 1978-89 period rather than the 1947-59 period used previously. Recharge and pumpage estimates should be better during the 1978-89 period and the Edwards Aquifer experienced a comparable range of water levels (as measured at J-17). Alternatively, both the 1947-59 and 1978-89 periods (or the entire 1934-89 period) could be used for calibration.

5. Estimates of historical recharge which occurred in the Upper San Marcos River watershed could be improved by consideration of daily surface water runoff estimates which were manually removed from gaged records on the San Marcos River during the annual processing of San Marcos springflows. It is our understanding that these records may exist in the USGS archives.

<u>Model Enhancements</u>

1. Incorporate program code to facilitate easy consideration of multiple drought management plan triggers or activities. Enhance capabilities to consider drought triggers keyed to monitoring wells in addition to J-17 or to Comal and San Marcos Springs. Improve capabilities to simulate activities such as irrigation purchase ("dry year option") or reduced pumpage in specific use categories / geographic areas. GWSIM4 should be capable of simulating redistribution and/or reduction of pumpage (by category of use and geographic region) on a monthly timestep based on springflow or well level triggers.

2. Improve/automate geographic distribution of historical recharge. Consider that most upstream cells on streams crossing the outcrop will have greatest opportunity for recharge and transmit "rejected" recharge (recharge in excess of cell storage capacity in a given month) to downstream cell(s).

3. Improve ability to retrieve specific data of interest from output of GWSIM4 model.

4. Update head-discharge relationships for all springs in GWSIM4 model. Consider non-linear or piecewise linear relationships for estimation of spring discharge from head levels if appropriate based on observed data. Also, consider possibility of different head-discharge relationships for rising and falling aquifer conditions. Any updated relationships would be determined based on historical well level and springflow data and, if significantly different, would replace those presently in GWSIM4.

5. Refine and/or incorporate relationships in the GWSIM4 model to simulate Edwards Aquifer flux at Hueco Springs and along the Guadalupe River between Canyon Dam and New Braunfels.

6. Modify model grid to include cell(s) in the Onion Creek watershed based on recent studies by LBG-Guyton for EUWD.

7. Consider bad water line location modifications in Medina and/or Uvalde Counties in accordance with recent EUWD study. . It is suggested that such modifications only be considered at this time if they will result in noticeably improved simulation results and will not alter existing grid size and shape.

8. Consider modifications (to the extent possible) to reflect improved geologic mapping being developed by the USGS for Hays, Comal, and Bexar Counties.

9. Formalize carry-over storage ("rejected" recharge) in the simulation of enhancement projects to following month. Ultimately, this kind of information needs to be tied back into surface water models.

10. Confirm extended cessation of discharges from Leona Springs simulated by the GWSIM4 model for annual pumpage rates of 400,000 acft and 450,000 acft.

11. Incorporate program code to facilitate simulation of surface water imports for recharge enhancement.

12. Consider modifications to account for various estimates of interformational flux from the Trinity Aquifer.

13. If model recalibration and enhancements significantly improve performance, consider development of program code to facilitate automated computation of Edwards Aquifer "firm yield" subject to various springflow and/or well level constraints.

14. Consider new capability to initialize heads throughout the aquifer for any time during the historical record. In order to perform simulations to predict potential future water levels and springflows, an accurate set of initial heads for cells comprising the aquifer for a given starting time should be generated based on available data from observation wells.

Edwards Aquifer
Recharge Enhancement Projects

TRANS-TEXAS WATER PROGRAM

WEST CENTRAL STUDY AREA

PHASE 2

GUADALUPE - SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY FEASIBILITY ASSESSMENT

San Antonio River Authority
San Antonio Water System
Edwards Aquifer Authority
Guadalupe-Blanco River Authority
Lower Colorado River Authority
Bexar Metropolitan Water District
Nueces River Authority
Canyon Lake Water Supply Corporation
Bexar-Medina-Atascosa Counties WCID No. 1
Texas Natural Resource Conservation Commission
Texas Parks and Wildlife Department
Texas Water Development Board

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March 1998

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3.0 RECHARGE ENHANCEMENT PROGRAM DEVELOPMENT

A range of storage capacities was examined for each proposed recharge enhancement project (except the Northern Bexar / Medina County projects) in order to determine an optimum size. In determining the range of storage capacities to evaluate, consideration was given to several factors including watershed area, site topography, and known site constraints that would increase project costs, such as major road relocations and inundation of structures. Five different storage capacities were evaluated for each of the four major recharge projects. For the five smaller projects in Northern Bexar and Medina County, the recharge pool volumes were set equal to the 100-year flood volume computed for each site.

The optimum size storage capacity for each major project was selected on the basis of the minimum unit cost of recharge enhancement under long-term (1934-1989) average conditions. Applying this criteria, the smallest storage capacity evaluated at each of the major projects was determined to be the optimum size.

During the individual project evaluations, it became apparent that the unit cost of recharge enhancement at the Upper Blanco site is considerably more expensive than that for the Lower Blanco site. Although the topography of the Upper Blanco site is very favorable for construction of a dam, the amount of water that could be recharged via releases across the downstream recharge zone and diversion from the reservoir to the Upper San Marcos watershed structures was significantly less than recharge enhancement at the Lower Blanco site. This resulted in unit costs for recharge enhancement, under both average and drought conditions, that were significantly higher than unit costs at the Lower Blanco site for all storage capacities evaluated. Given this, the Upper Blanco site was eliminated from consideration in the development of the recharge enhancement program for the Guadalupe - San Antonio River Basin. It should be noted, however, that the Upper Blanco project may have indirect water supply benefits such as more definitive control (with respect to timing) of the water to be used for recharge enhancement.

3.1 Sizing of Projects in Guadalupe - San Antonio River Basin

On the basis of this study, the Cibolo Creek, Lower Blanco, and San Geronimo Creek recharge enhancement projects are believed to be ready to move forward to a preliminary design and permitting phase at this time. The recommended size of each major project was determined by examining the unit cost of recharge enhancement under average conditions for each of the storage capacities evaluated. The sizing procedure began by selecting the storage capacity of each project having the lowest unit cost (i.e., optimum size) and continued by enlarging the projects up to the maximum storage capacity considered.

Table 3.1-1 illustrates this process. The Cibolo Creek project at its optimum size represents the lowest unit cost of recharge enhancement of the three (Upper Blanco excluded) major projects. The next most cost effective quantity of recharge enhancement is obtained by developing the Lower Blanco project at its optimum size. The third most cost effective increment of recharge enhancement is obtained by enlarging the storage capacity of the Cibolo Creek project from 1,000 to 5,000 acft. The San Geronimo Creek project at its optimum (smallest) size enters the program ranked fourth. The program development continues by evaluating the incremental cost to enlarge each project up to the maximum storage capacity considered for each of the projects.

Graphical presentations of the recharge program development are shown in Figures 3.1-1 and 3.1-2. The points on the graphs correspond to the unit or incremental cost rankings as presented in Table 3.1-1. A fairly well defined break point occurs in the program development process at the 11th ranked project. This point represents the Lower Blanco project developed to its full potential storage capacity of 50,000 acft. Beyond this point, the unit cost of recharge enhancement begins to increase sharply, as relatively small amounts of additional recharge enhancement are added to the program. Figure 3.1-2 illustrates that virtually no additional recharge enhancement during the 10-year drought period (1947-1956) is added beyond the 11th ranked project.

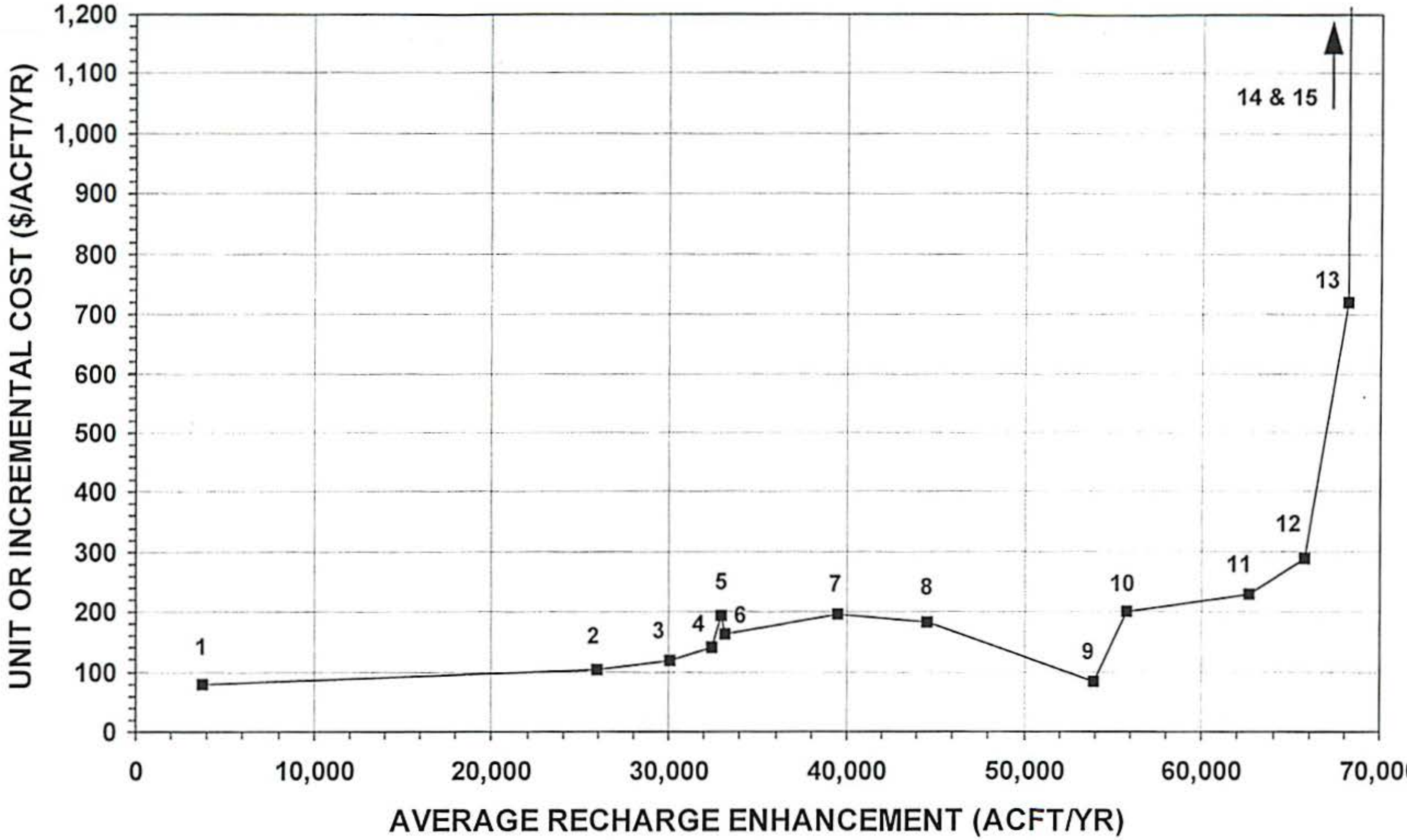
The 12th step in the program development represents enlarging the storage capacity at the Cibolo Creek project from 10,000 to 50,000 acft. Detailed geohydrological investigations will be necessary for this larger size to determine if the potential environmental and socioeconomic impacts to Bracken Bat Cave and Natural Bridge Caverns[1] are worth the relatively small

[1] Natural Bridge Caverns, Various letters to U.S. National Park Service and San Antonio River Authority, April 4, 1995 to April 2, 1996.

Table 3.1-1
Guadalupe-San Antonio River Basin
Recharge Enhancement Program Development

Cost Ranking[1]	Average Unit or Incremental Cost to Enlarge ($/acft/yr)	Project	Optimum or Enlarged Storage Capacity (acft)	Recharge Enhancement (acft/yr)	
				Average Conditions	Drought Conditions
1	80	Cibolo Creek	1,000	3,787	382
2	104	Lower Blanco	3,500	22,129	9,789
		Subtotals	4,500	25,916	10,171
3	120	Cibolo Creek	5,000	4,138	550
		Subtotals	8,500	30,054	10,721
4	142	San Geronimo	350	2,375	528
		Subtotals	8,850	32,429	11,249
5	193	San Geronimo	1,000	505	102
		Subtotals	9,500	32,934	11,351
6	164	San Geronimo	3,500	248	15
		Subtotals	12,000	33,182	11,366
7	196	Lower Blanco	10,000	6,348	3,471
		Subtotals	18,500	39,530	14,837
8	183	Lower Blanco	17,500	5,078	2,225
		Subtotals	26,000	44,608	17,062
9	83	Lower Blanco	35,000	9,349	3,807
		Subtotals	43,500	53,957	20,869
10	201	Cibolo	10,000	1,808	553
		Subtotals	48,500	55,765	21,422
11	230	Lower Blanco	50,000	6,862	3,198
		Subtotals	63,500	62,627	24,620
12	288	Cibolo Creek	50,000	3,116	984
		Subtotals	103,500	65,734	25,604
13	720	Bexar/Medina Sites	12,409	2,429	501
		Subtotals	115,909	68,172	26,105
14	2,124	San Geronimo	7,000	75	6
		Subtotals	119,400	68,247	26,111
15	31,897	San Geronimo	14,000	28	10
		Subtotals	126,409	68,275	26,121

[1]Ranking is based on unit or incremental cost of recharge enhancement for average conditions.



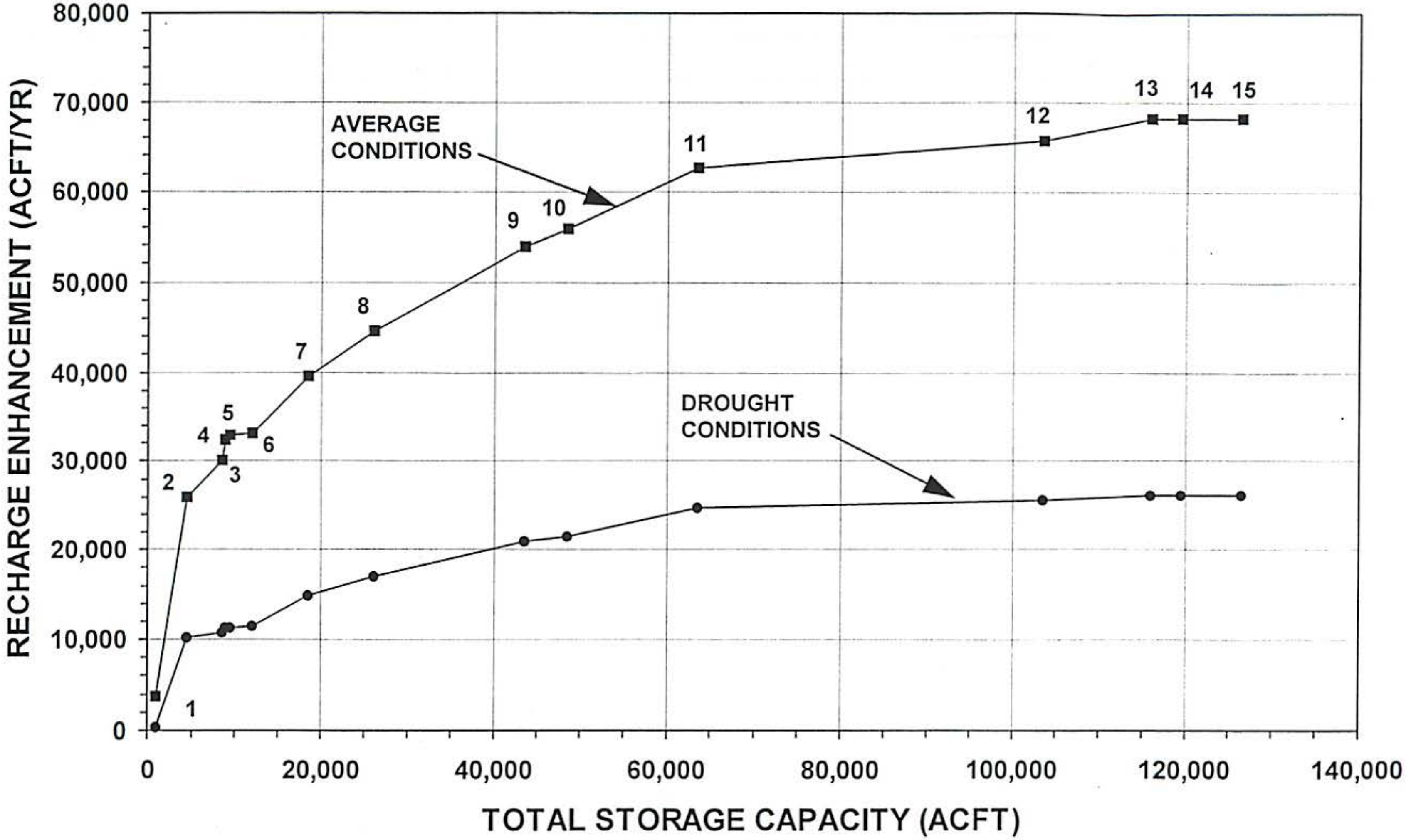
GUADALUPE - SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY
FEASIBILITY ASSESSMENT

HDR Engineering, Inc.

TRANS TEXAS WATER PROGRAM /
WEST CENTRAL STUDY AREA

RECHARGE ENHANCEMENT PROGRAM DEVELOPMENT COST SUMMARY

FIGURE 3.1-1



GUADALUPE - SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY
FEASIBILITY ASSESSMENT

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RECHARGE ENHANCEMENT PROGRAM DEVELOPMENT STORAGE SUMMARY

FIGURE 3.1-2

amounts of additional average and drought recharge enhancement obtained by enlarging the project. Other potential benefits, although not addressed by this study, may exist for an enlarged project. These may include flood control and use of the enlarged recharge pool as a discharge location for imported water.

The group of five smaller Northern Bexar / Medina County projects enters the program ranked 13th, with a unit cost for recharge enhancement of $720/acft/yr under average conditions, as shown in Table 3.1-1. Although the cost of recharge enhancement appears to be very high for these smaller projects, other benefits such as flood control, may be derived from the development of these projects in the growing northwestern suburbs of San Antonio. These projects may also be utilized as discharge locations for water imported to enhance recharge and/or recirculation of Edwards Aquifer springflow.

3.2 Summary of Recommended Recharge Enhancement Program for Guadalupe - San Antonio River Basins (L-21)

The recommended recharge enhancement program is comprised of the Cibolo Creek project sized at 10,000 acft, Lower Blanco at 50,000 acft with diversion to the Upper San Marcos watershed flood retardation structures, and San Geronimo Creek at 3,500 acft. A summary of the recommended program is presented in Table 3.2-1. Development of this program would provide 62,627 acft/yr of recharge enhancement under average conditions at an average unit cost of $135/acft/yr ($0.41 per 1,000 gallons). Recharge enhancement under drought conditions would be 24,620 acft/yr at an average unit cost of $344/acft/yr ($1.06 per 1,000 gallons). The total capital cost of the recommended recharge enhancement program is estimated to be $81.8 million and the total annual cost for this program would be about $8.5 million.

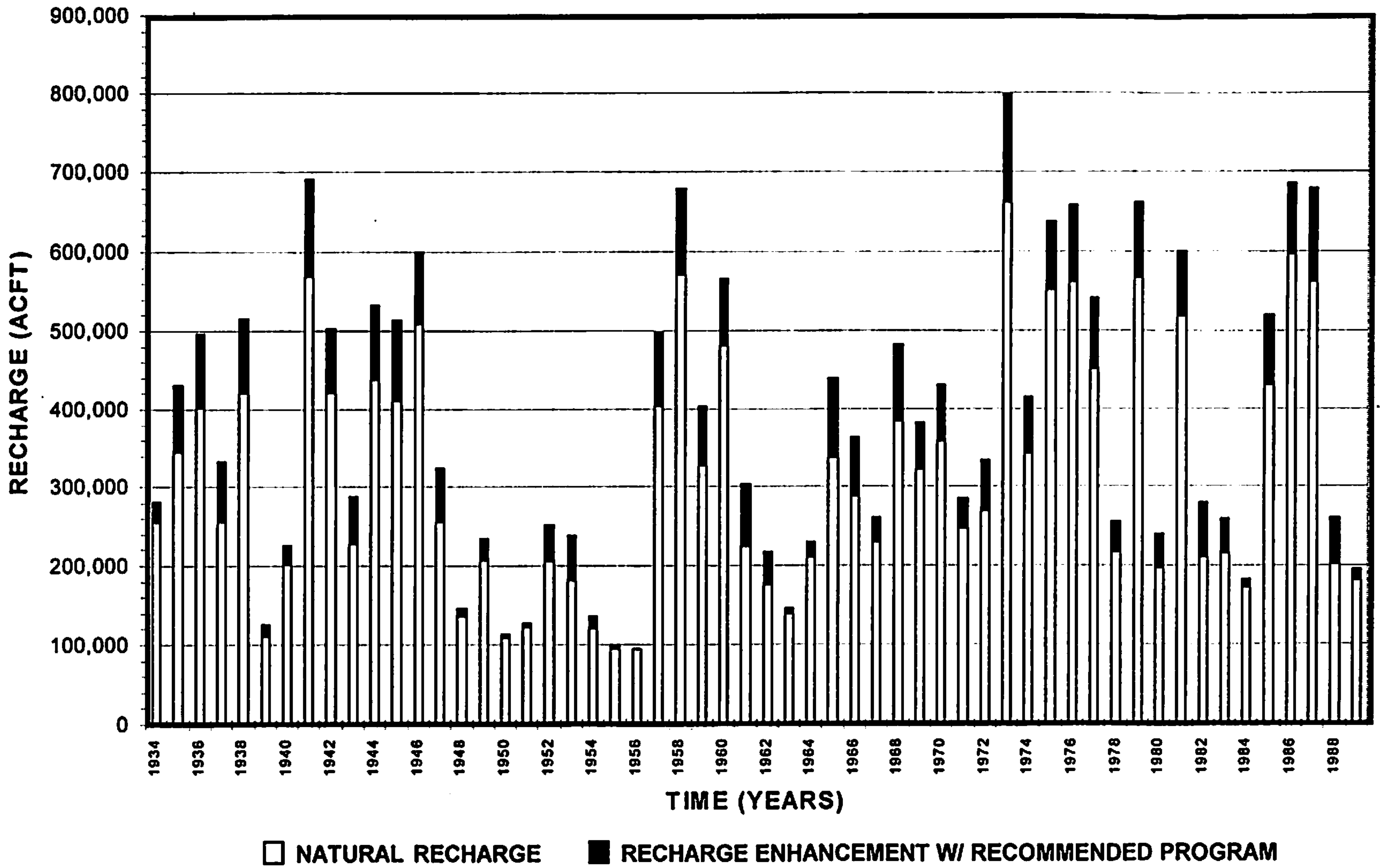
A graph showing how the annual recharge to the Edwards Aquifer occurring in the Guadalupe - San Antonio River Basin would be affected by implementation of the recommended program is presented in Figure 3.2-1. This figure illustrates natural recharge to the Edwards Aquifer and recharge enhancement resulting from development of the recommended program. Recharge to the Guadalupe - San Antonio River Basin portion of the Edwards Aquifer would be increased by approximately 20 percent under average conditions and 16 percent under drought conditions with the implementation of the recommended recharge enhancement program.

Table 3.2-1

Summary of Recommended Recharge Enhancement Program for Guadalupe-San Antonio River Basin

Rank*	Project	Capacity (acft)	Surface Area (ac)	Annual Cost ($)	Average Conditions: Recharge Enhancement (acft/yr)	Average Conditions: Cost/Unit Recharge Enhancement ($/acft/yr)	Drought Conditions: Recharge Enhanceme nt (acft/yr)	Drought Conditions: Cost/Unit Recharge Enhancement ($/acft/yr)
1	Cibolo Creek	10,000	476	1,165,724	9,733	120	1,485	785
2	Lower Blanco	50,000	1,408	6,830,020	49,766	137	22,490	304
3	San Geronimo	3,500	183	475,476	3,128	152	645	737
	Total	63,500	2,067	8,471,220	62,627		24,620	
	Average					135		344

*Rank is based on cost/unit recharge enhancement for average conditions.



TRANS TEXAS WATER PROGRAM / WEST CENTRAL STUDY AREA

EDWARDS AQUIFER RECHARGE GUADALUPE-SAN ANTONIO RIVER BASIN

FIGURE 3.2-1

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GUADALUPE - SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY FEASIBILITY ASSESSMENT

Cumulative downstream impacts associated with the program are represented by changes in streamflow at the Saltwater Barrier, as presented in Figure 3.2-2. Based on the minimal reduction in estuarine inflow, potential impacts to fisheries harvest, salinity fluctuations, and nutrient/sediment loadings are likely to be insignificant as a result of development of the recommended recharge enhancement program in the Guadalupe - San Antonio River Basin. Long-term average annual streamflows at the Saltwater Barrier would decrease approximately 2.5 percent from 1,625,115 acft/yr without recharge enhancement to 1,585,088 acft/yr with the three recommended projects. This represents a maximum upper limit of impact, since enhanced springflows resulting from the additional recharge will reduce these impacts. Median monthly flow changes with the projects range from a maximum decrease due to the projects of 4,855 acft per month (7 percent) in April to a minimum decrease of 272 acft per month (0.3 percent) in June.

3.3 Combined Program for Nueces and Guadalupe - San Antonio River Basins (L-18A)

A recharge enhancement study for the Nueces River Basin was completed by the EUWD in June, 1994.[2] The recommended recharge enhancement program resulting from that study consisted of four projects, each constructed at its optimum size. These projects included, from east to west, the Lower Verde, Hondo, Sabinal, and Frio Projects. As discussed in Section 3.1 for the Cibolo Creek and Bexar/Medina County projects in the Guadalupe — San Antonio Basin, the recharge projects in the Nueces River Basin could be enlarged to obtain additional flood control benefits and/or to facilitate recharge of imported water. For comparison purposes in this study, capital costs for the recommended Nueces River Basin projects were updated from mid-1994 to the first quarter 1996 level using U.S. Bureau of Reclamation Construction Cost Indices (USBR CCI) for earth or concrete dams (as appropriate) and for secondary road relocations. Land acquisition costs were held constant and environmental mitigation costs were inflated by seven percent over the 21-month period. Total capital costs were annualized using an interest rate of eight percent for 25 years. The total capital cost of the Nueces River Basin

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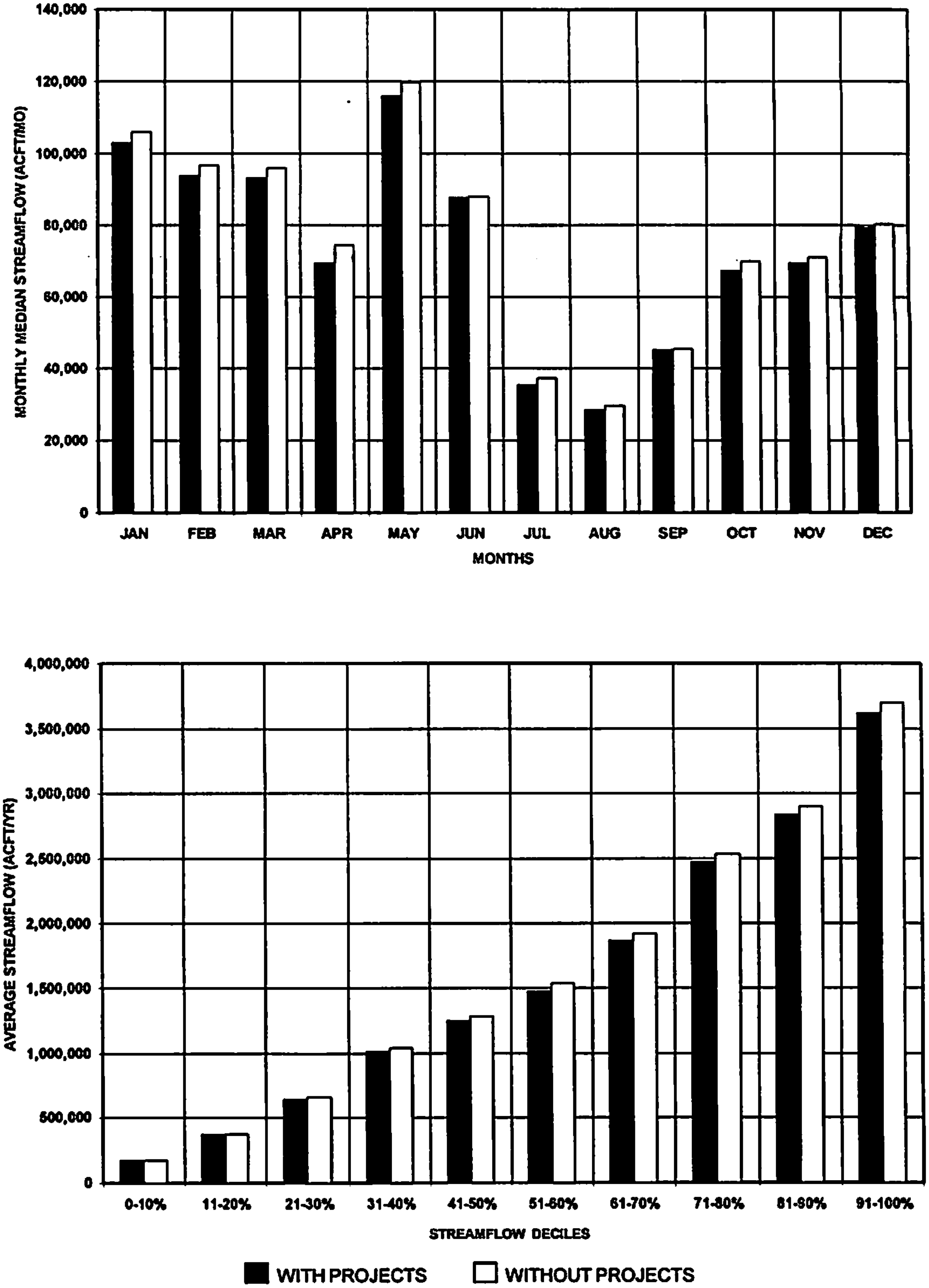
[2] HDR Engineering, Inc., "Nueces River Basin Edwards Aquifer Recharge Enhancement Project, Phase IVA," Edwards Underground Water District, June, 1994.



GUADALUPE - SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY
FEASIBILITY ASSESSMENT

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RECHARGE ENHANCEMENT PROGRAM
CHANGES IN STREAMFLOW
AT SALT WATER BARRIER

FIGURE 3.2-2

recharge enhancement program is estimated to be $60.0 million and the total annual cost for this program would be about $7.0 million.

A summary of the recommended recharge enhancement program for the Nueces River Basin is presented in Table 3.3-1. Development of this program would provide 45,135 acft/yr of recharge enhancement under average conditions at an average unit cost of $156/acft/yr ($0.48 per 1,000 gallons). Recharge enhancement under drought conditions would be 9,250 acft/yr at an average unit cost of $760/acft/yr ($2.33 per 1,000 gallons). Costs to mitigate impacts to the Choke Canyon Reservoir / Lake Corpus Christi System yield and reductions in fresh water inflows to the Nueces Estuary were included in the development of project costs.

A combined recharge enhancement program for the Edwards Aquifer has been developed by ranking the recommended projects in the Nueces and Guadalupe - San Antonio River Basins based on the unit cost of recharge enhancement under average conditions. The combined recharge enhancement program is presented in Table 3.3-2. Graphical presentations of this program are shown in Figures 3.3-1 and 3.3-2. Development of this combined program could provide 107,762 acft/yr of recharge enhancement under average conditions at an average unit cost of $144/acft/yr ($0.44 per 1,000 gallons). Recharge enhancement under drought conditions would be 33,870 acft/yr at an average unit cost of $458/acft/yr ($1.41 per 1,000 gallons). The total capital cost of the combined Edwards Aquifer recharge enhancement program is estimated to be $141.8 million and the total annual cost for this program would be about $15.5 million.

As shown in Table 3.3-2, the Lower Blanco project represents a significant portion of the recharge enhancement under both long-term and drought average conditions. The calculation of potential recharge enhancement and, therefore, the unit cost of enhancement is a function of the natural percolation rate used for the recharge pool in the model. Detailed geologic and hydrogeologic investigations of the Lower Blanco reservoir area will be necessary to determine natural and expected recharge rates and the subsequent movement of ground water from the site. A similar conclusion was reached for the proposed Indian Creek project on the Nueces River in the 1994 Nueces River Basin recharge enhancement study.

Table 3.3-1

Summary of Recharge Enhancement Program for Nueces River Basin

Rank*	Project	Capacity (acft)	Surface Area (ac)	Annual Cost ($)	Average Conditions: Recharge Enhancement (acft/yr)	Average Conditions: Cost/Unit Recharge Enhancement ($/acft/yr)	Drought Conditions: Recharge Enhancement (acft/yr)	Drought Conditions: Cost/Unit Recharge Enhancement ($/acft/yr)
1	Lower Sabinal	8,750	454	1,420,829	16,442	86	2,358	603
2	Lower Verde	3,600	334	647,148	4,850	133	1,719	376
3	Lower Hondo	2,800	232	1,335,515	6,779	197	1,193	1,119
4	Lower Frio	17,500	1,099	3,628,170	17,064	213	3,980	912
	Total	32,650	2,119	7,031,662	45,135		9,250	
	Average					156		760

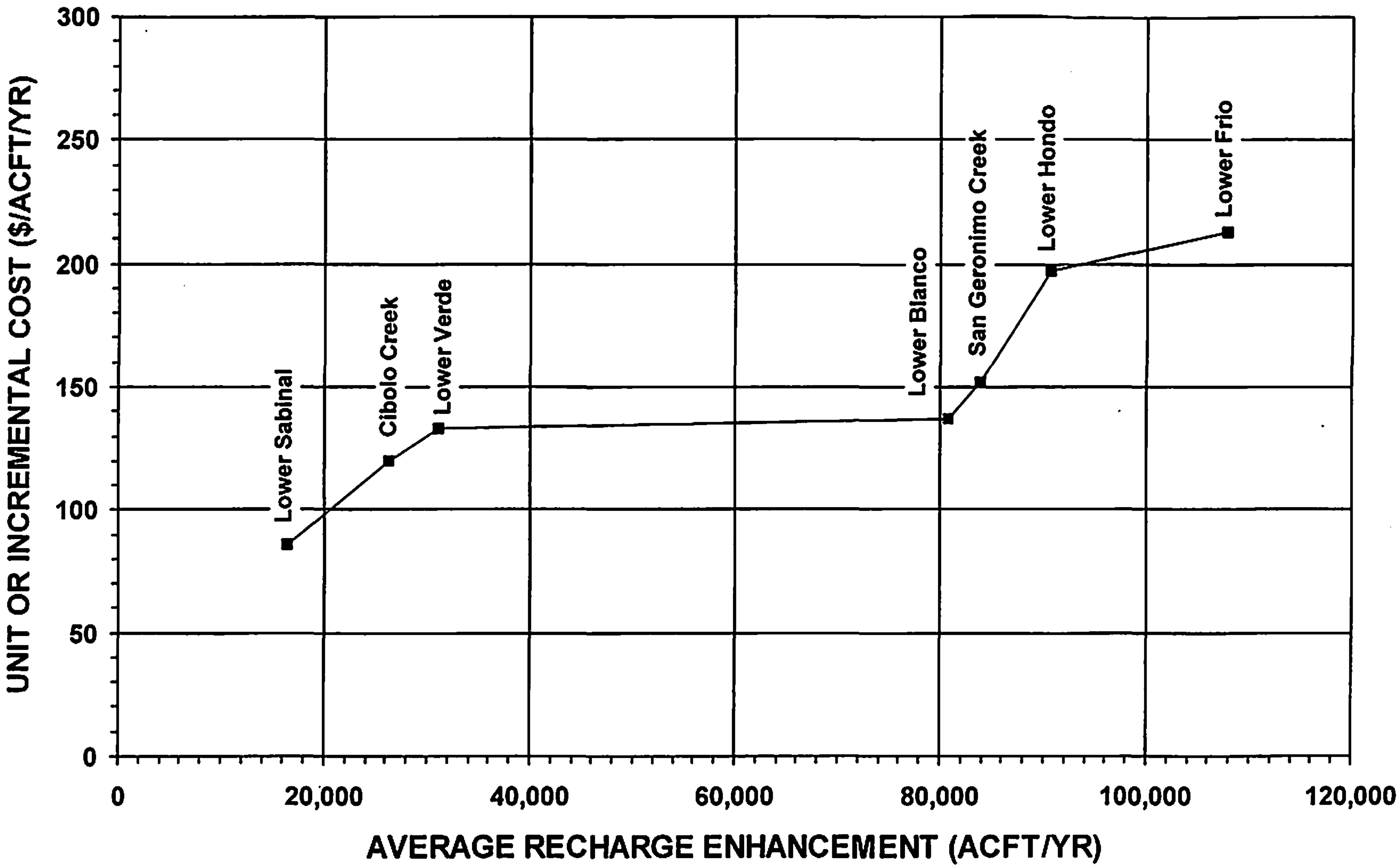
*Rank is based on cost/unit recharge enhancement for average conditions.

Table 3.3-2

Combined Recharge Enhancement Program for Edwards Aquifer

Rank*	Project	Capacity (acft)	Surface Area (ac)	Annual Cost ($)	Average Conditions		Drought Conditions	
					Recharge Enhancement (acft/yr)	Cost/Unit Recharge Enhancement ($/acft/yr)	Recharge Enhancement (acft/yr)	Cost/Unit Recharge Enhancement ($/acft/yr)
1	Lower Sabinal	8,750	454	1,420,829	16,442	86	2,358	603
2	Cibolo Creek	10,000	476	1,165,724	9,733	120	1,485	785
3	Lower Verde	3,600	334	647,148	4,850	133	1,719	376
4	Lower Blanco	50,000	1,408	6,830,020	49,766	137	22,490	304
5	San Geronimo	3,500	183	475,476	3,128	152	645	737
6	Lower Hondo	2,800	232	1,335,515	6,779	197	1,193	1,119
7	Lower Frio	17,500	1,099	3,628,170	17,064	213	3,980	912
	Total	96,150	4,186	15,502,882	107,762		33,870	
	Average					144		458

*Rank is based on cost/unit recharge enhancement for average conditions.



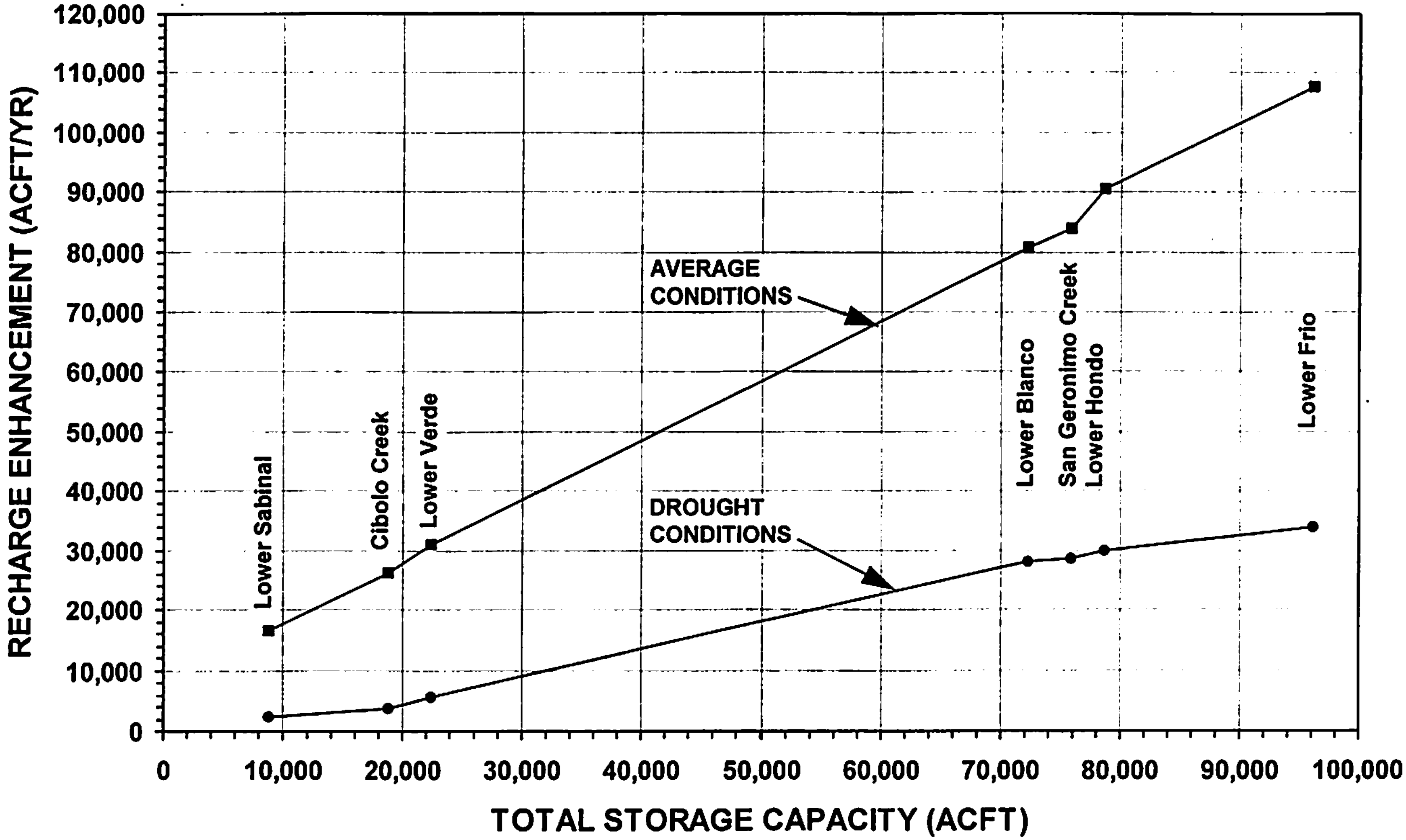
TRANS TEXAS WATER PROGRAM / WEST CENTRAL STUDY AREA

RECHARGE ENHANCEMENT PROGRAM FOR COMBINED BASINS - COST SUMMARY

GUADALUPE - SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY
FEASIBILITY ASSESSMENT

HDR Engineering, Inc.

FIGURE 3.3-1



GUADALUPE - SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY
FEASIBILITY ASSESSMENT

HDR

HDR Engineering, Inc.

TRANS TEXAS WATER PROGRAM /
WEST CENTRAL STUDY AREA

RECHARGE ENHANCEMENT PROGRAM FOR COMBINED BASINS - STORAGE SUMMARY

FIGURE 3.3-2

Development of the Lower Blanco recharge project would likely result in sustained increases in flow from San Marcos Springs. These additional flows could be recaptured from the Guadalupe River below the San Marcos River confluence and diverted back to the Edwards Aquifer via a pipeline to the recharge zone. Conceptual studies on springflow recirculation (Alternatives L-22 and L-23) indicate that water diverted below Comal and or San Marcos Springs and introduced to the aquifer in northern Bexar County significantly benefits Comal Springs discharge thereby allowing more sustained pumpage during drought. Transferring water further west into Medina and/or Uvalde Counties could further elevate long-term storage levels in the aquifer, also increasing reliability of both pumpage and springflows during drought. Implementation of the recharge enhancement projects identified in this study is a key component in the overall management of the Edwards Aquifer.

To fully evaluate the potential benefits of implementing the recommended recharge program, it is recommended that the TWDB's GWSIM4 Model be used to evaluate the effects on increased aquifer pumpage and/or springflows. A systematic incremental analysis in which the enhanced recharge volumes produced by each recharge structure are incorporated into the groundwater model would clearly demonstrate the beneficial effects of each structure on aquifer pumpage and/or springflows. Additionally, this analysis should consider the combined benefits of implementing the recommended recharge program in combination with springflow recirculation.

Recirculation Concepts for Recharge Enhancement

EDWARDS AQUIFER – SAN ANTONIO

SPRINGFLOW RECIRCULATION AND RECHARGE ENHANCEMENT

March 9, 1998

What have we learned?

- Springflow Recirculation

  1. Northwestern Bexar County

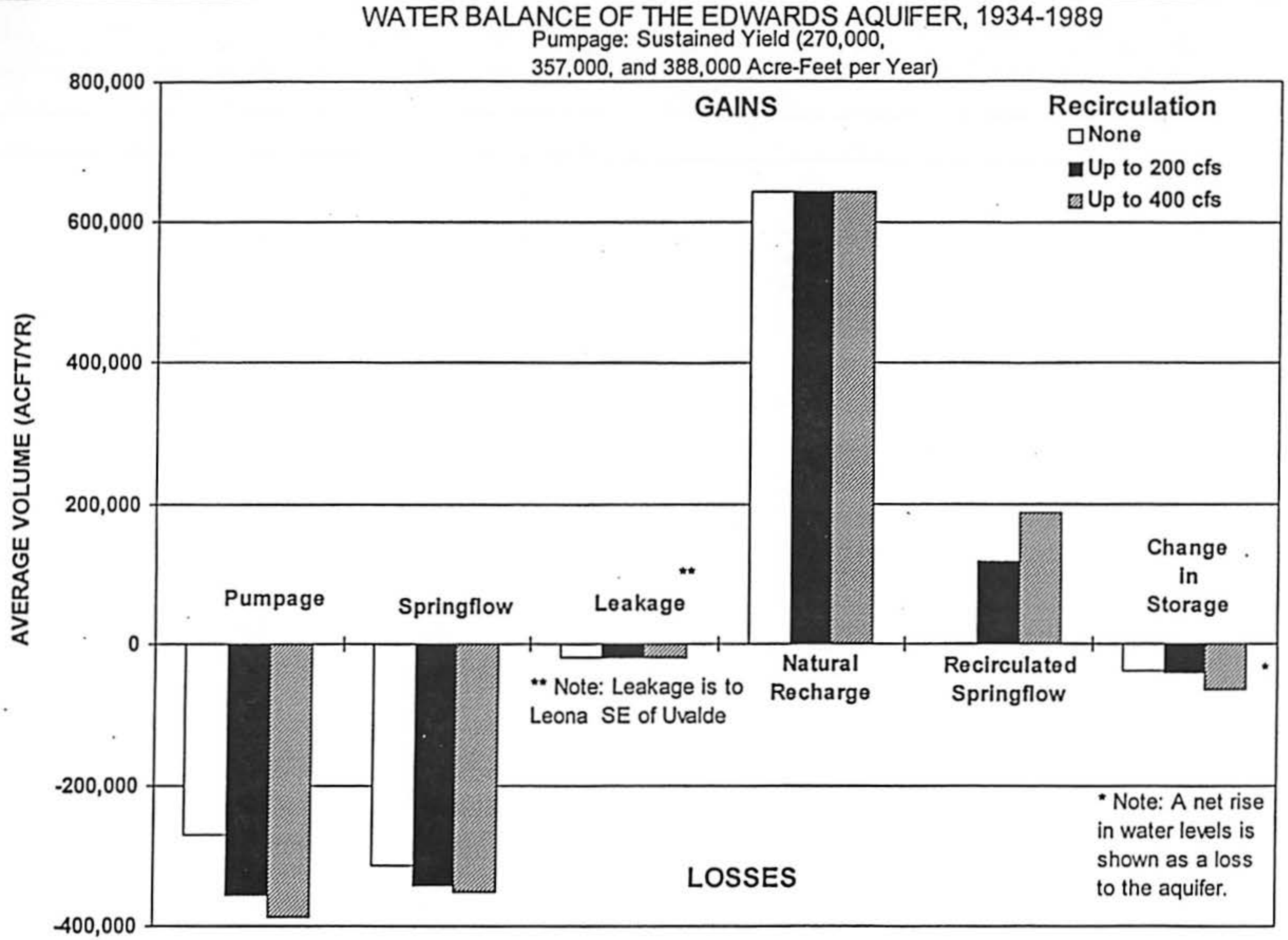
     - For a recirculation rate of up to 200 cfs, an average of about 116,000 acft/yr would be available for recirculation;
     - About 75 percent of the recirculation (i.e., 87,000 ac-ft/yr) can be pumped from the aquifer and still sustain critical flows at Comal Springs;
     - Comal Springs begins to respond to recharge within a month or so and reaches a new equilibrium in about 10 years; and
     - Long-term Unit cost of water recharged to the aquifer is about $260/acft/yr. The cost for water available for pumping is $ 350/acft/yr.
     - For a "sustained yield" pumpage and 200 cfs recirculation to NW Bexar County, the average flow in the Guadalupe River decreased by 97 cfs. However, the decrease in flows during the drought were considerably less. (See attached graphs)
     - Water rights at the Saltwater Barrier generally decreased about 6,000 ac-ft/mo for the 200 cfs recirculation rate. (See Table) There is a very good potential of reducing or eliminating the impact by turning the recirculation 'OFF' during critical times.

2. Medina County

- When operated in conjunction with northwestern Bexar County, recharge increases by about a third;
    - Additional Long-term Recirculation Volume is 69,000 acft/yr;
    - Additional Drought (1947-1956) Recirc. Vol. is 21,500 acft/yr; and
    - Additional "Sustained Yield" Pumpage is 31,000 acft/yr.
        - (Note: 31,000 acft/yr is 45 percent of the long term recirculation volume and 144 percent of the drought recirculation volume.)
- Comal Springs response is very delayed, taking several decades for a new equilibrium to be established;
- Incremental Unit cost (long-term) is about than five times more expensive than recharge to northwestern Bexar County; and
- Recharge projects are more economical way to enhance recharge in Medina County.

- Recharge Enhancement

  See Table



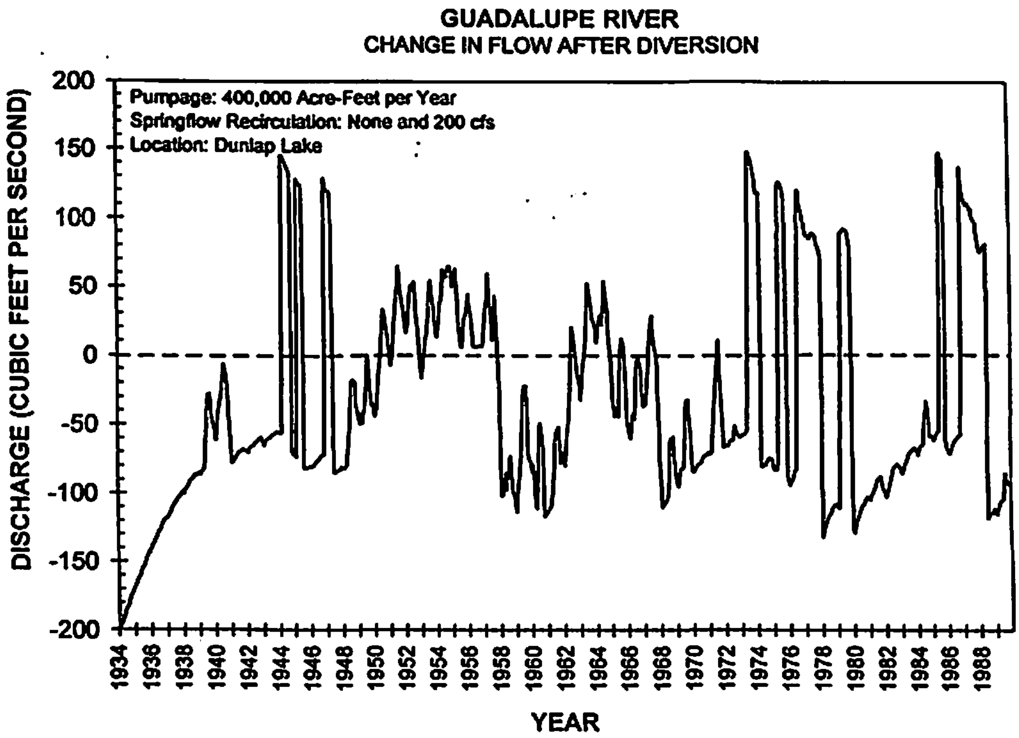
TRANS TEXAS WATER PROGRAM / WEST CENTRAL STUDY AREA

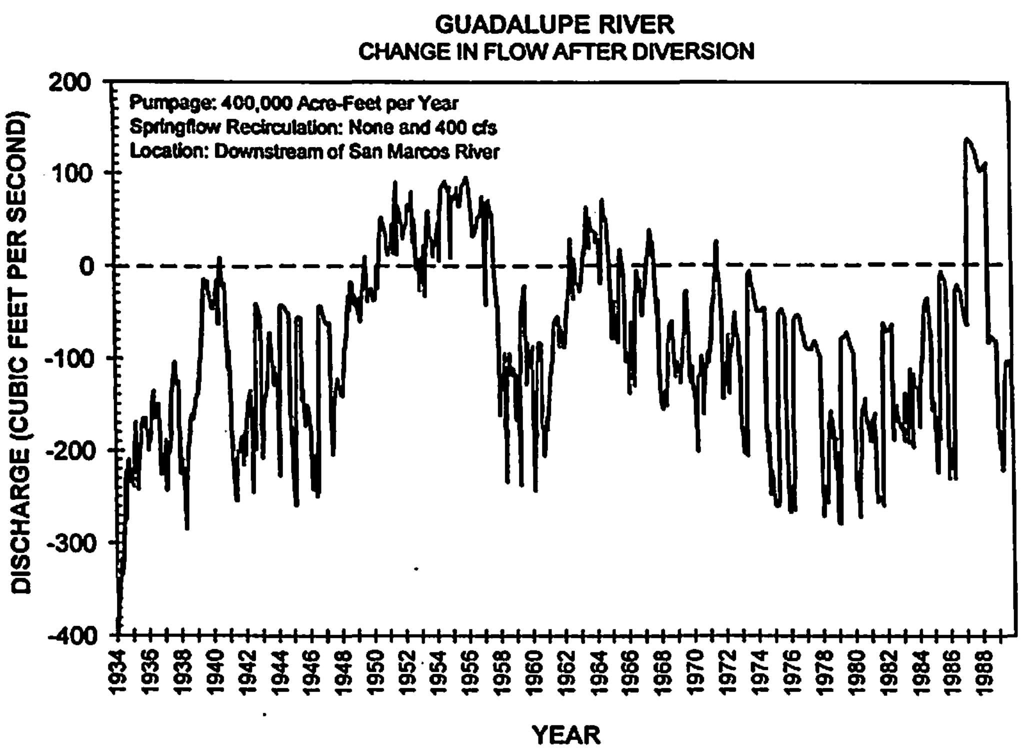
WATER BUDGET
"SUSTAINED YIELD" PUMPAGE

FIGURE 3.2-2

HDR Engineering, Inc.

CONCEPTUAL EVALUATION OF SPRINGFLOW RECIRCULATION





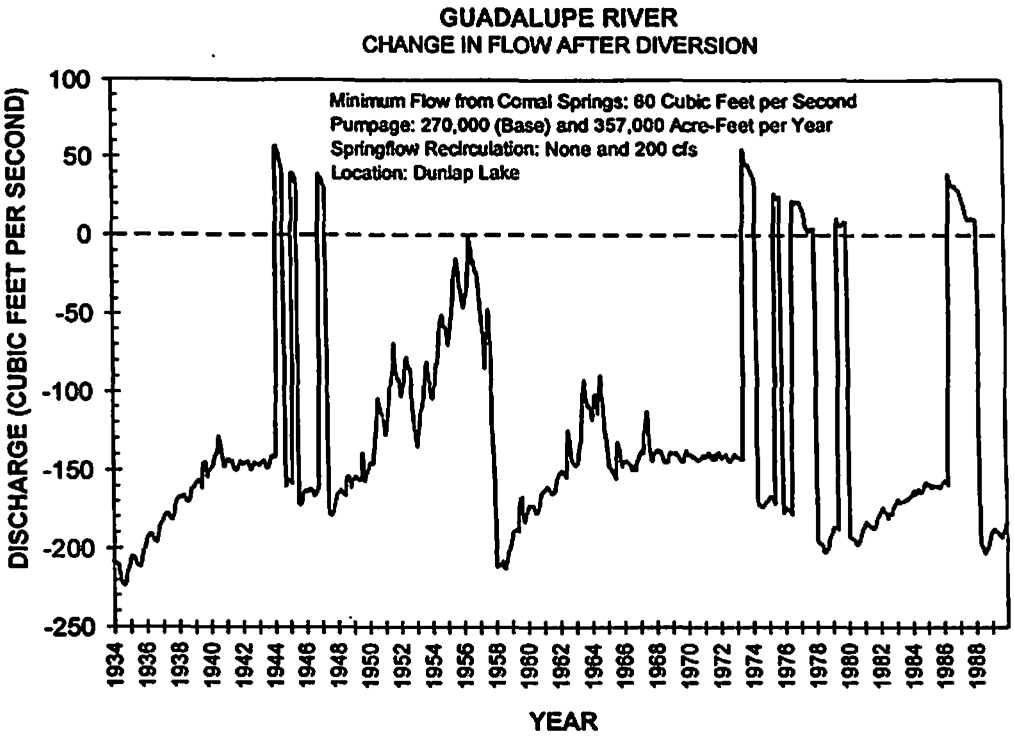
CONCEPTUAL EVALUATION OF SPRINGFLOW RECIRCULATION

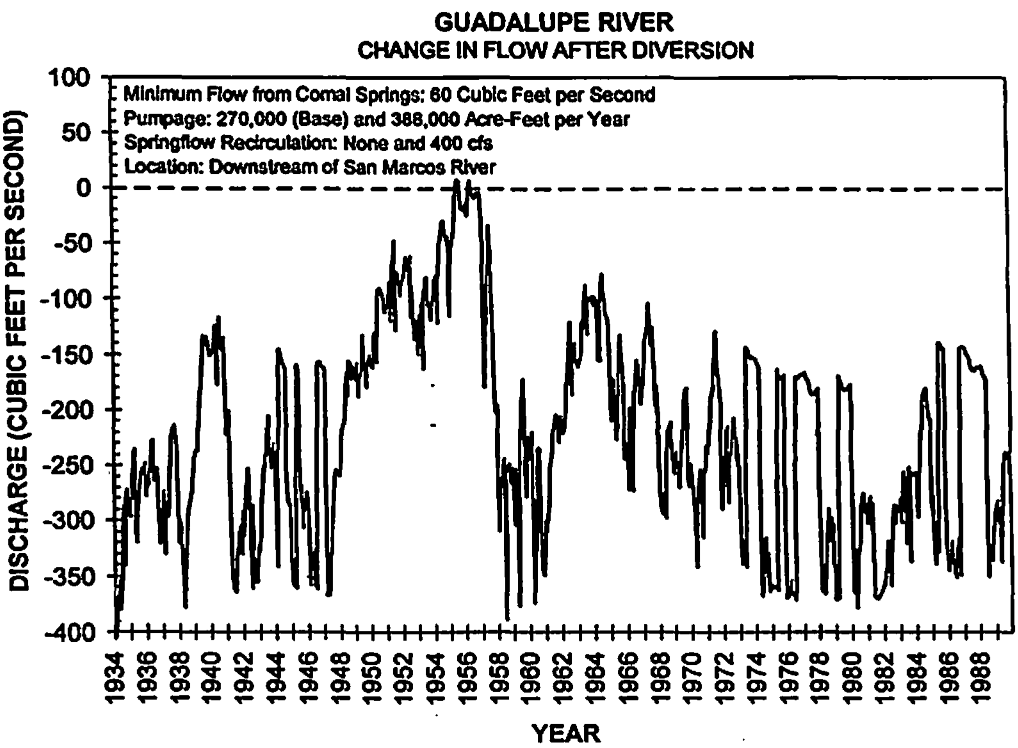
TRANS TEXAS WATER PROGRAM / WEST CENTRAL STUDY AREA

HDR Engineering, Inc.

COMPUTED CHANGE IN FLOW GUADALUPE RIVER AFTER DIVERSION
400,000 ACFT/YR PUMPAGE

FIGURE 3.1-5





CONCEPTUAL EVALUATION OF SPRINGFLOW RECIRCULATION

TRANS TEXAS WATER PROGRAM / WEST CENTRAL STUDY AREA

HDR Engineering, Inc.

COMPUTED CHANGE IN FLOW GUADALUPE RIVER AFTER DIVERSION "SUSTAINED YIELD" PUMPAGE

FIGURE 3.2-5

Table 3.2-1.
Summary of Water Rights Shortages and Canyon Reservoir Firm Yield for "Sustained Yield" Pumpage

		Shortage or Yield in ac-ft/yr				
Location	**Total Water Rights (ac-ft)**	**Baseline no Recirculation**	**Up to 200 cfs Recirculation**	**Δ**	**Up to 400 cfs Recirculation**	**Δ**
Long-Term (1934-89) Average						
Guadalupe Riv.,Victoria	23,806	0	0	0	0	0
Guadalupe Riv., Saltwater Barrier	220,433	4,862	7,092	2,230	8,054	3,192
San Antonio Riv., Falls City	9,311	0	0	0	0	0
Drought (1947-56) Average						
Guadalupe Riv.,Victoria	23,806	0	0	0	0	0
Guadalupe Riv., Saltwater Barrier	220,433	18,887	23,789	4,901	24,112	5,225
San Antonio Riv., Falls City	9,311	0	0	0	0	0
Canyon Lake firm yield		87,124	86,492	-632	86,253	-871

Table 3.3-2 Combined Recharge Enhancement Program for Edwards Aquifier								
					Average Conditions		Drought Conditions	
Rank*	Project	Capacity (acft)	Surface Area (ac)	Annual Cost ($)	Recharge Enhancement (acft/yr)	Cost/Unit Recharge Enhancement ($/acft/yr)	Recharge Enhancement (acft/yr)	Cost/Unit Recharge Enhancement ($/acft/yr)
1	Lower Sabinal	8,750	454	1,420,829	16,442	86	2,358	603
2	Cibolo Creek	10,000	476	1,165,724	9,733	120	1,485	785
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7	Lower Frio	17,500	1,099	3,628,170	17,064	213	3,980	912
	Total	96,150	4,186	15,502,882	107,762		33,870	
	Average					144		458

*Rank is based on cost/unit recharge enhancement for average conditions.

Estimated "Sustained Yield" Pumpage : Insufficient Information.
Spr. Recir

116,000 260

Table 3.3-1

Summary of Recharge Enhancement Program for Nueces River Basin

Rank*	Project	Capacity (acft)	Surface Area (ac)	Annual Cost ($)	Average Conditions: Recharge Enhancement (acft/yr)	Average Conditions: Cost/Unit Recharge Enhancement ($/acft/yr)	Drought Conditions: Recharge Enhancement (acft/yr)	Drought Conditions: Cost/Unit Recharge Enhancement ($/acft/yr)
1	Lower Sabinal	8,750	454	1,420,829	16,442	86	2,358	603
2	Lower Verde	3,600	334	647,148	4,850	133	1,719	376
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4	Lower Frio	17,500	1,099	3,628,170	17,064	213	3,980	912
	Total	32,650	2,119	7,031,662	45,135		9,250	
	Average					156		760

*Rank is based on cost/unit recharge enhancement for average conditions.

Estimated "Sustained Yield" Pumpage 20,300 [1] 13,300 [2]

Notes: [1] 45% of Total
[2] 144% of Total

Where do we go from here?

1. To more fully evaluate the potential benefits of springflow recirculation, it is recommended that the current version of GWSIM4 be improved to more accurately evaluate potential and recommended springflow recirculation and recharge enhancement projects. These improvements should include:
    - the ability to easily modify starting head conditions within the model,
    - a reevaluation of the head-discharge relationships at each spring, especially at San Antonio, San Pedro, and Leona Springs,
    - a consideration of discharge from Hueco Springs and any recharge from the Guadalupe River, and
    - a consideration of recharge coming from Onion Creek which may improve simulations at San Marcos Springs. Consider GWSIM4 "improvement" of springflow discharge and water levels, especially in the San Antonio area. This would include:
2. After GWSIM4 is improved, it is recommended that the following analysis be performed to fully evaluate the benefits of the recharge enhancement projects on the basis of "sustained yields" and unit cost of increased "sustained yields" both with and without springflow recirculation.
    - Use GWSIM4 to determine in a systematic manner "sustained yield" pumpage and associated unit costs for individual or groups of recommended recharge projects. This would be done initially without recirculation;
    - Use GWSIM4 to detemine optimum recirculation rate from Lake Dunlap with recommended recharge projects in place and determine "sustained yield" and unit costs for a range of recirculation rates. Consider adding other water sources, i.e., unappropriated water, unutilized water rights, or purchased water rights at Lake Dunlap. Also, consider the water supply benefits and costs of extending the recirculation pipeline to Medina Lake on both aquifer yield and reservoir yield. (Note: This analysis is intended to determine the upper limit of

aquifer pumpage for the combined effects of multiple recharge projects and water sources.)

- Determine optimum combination of recharge projects and recirculation rate by a systematic elimination of selected recharge projects to determine increased "sustained yield" and unit costs with recirculation in place; and
- Recommend optimum system and consider institutional and permitting issues associated with implementation to allow for pumping and springflow benefits to be fully realized.

General Questions and Comments

- Can surplus springflow recirculation be spilled into Medina Lake with credit for some of the water becoming recharge to the Edwards and some being withdrawn from Medina River?
- Can recirculation be turned 'OFF' during critical times to meet downstream senior water rights in the Guadalupe River?
- Can recirculated springflow in combination with other water sources be treated and delivered directly to municipal distribution system during high demand periods (summer) or when aquifer storage is 'full'?
- What is the most efficient way to recharge the recirculated springflow?
- Will injection wells be needed as a backup if target streams reject recharge?
- What are some of the other beneficial uses of recharge facilities?
- How can a recharge project in the Blanco River be used to benefit water users in the San Antonio area? For example, can enhanced springflow help ensure 100 cfs minimum at San Marcos Springs and/or potentially help mitigate reduced flows on the Guadalupe River caused by recirculation from Lake Dunlap?