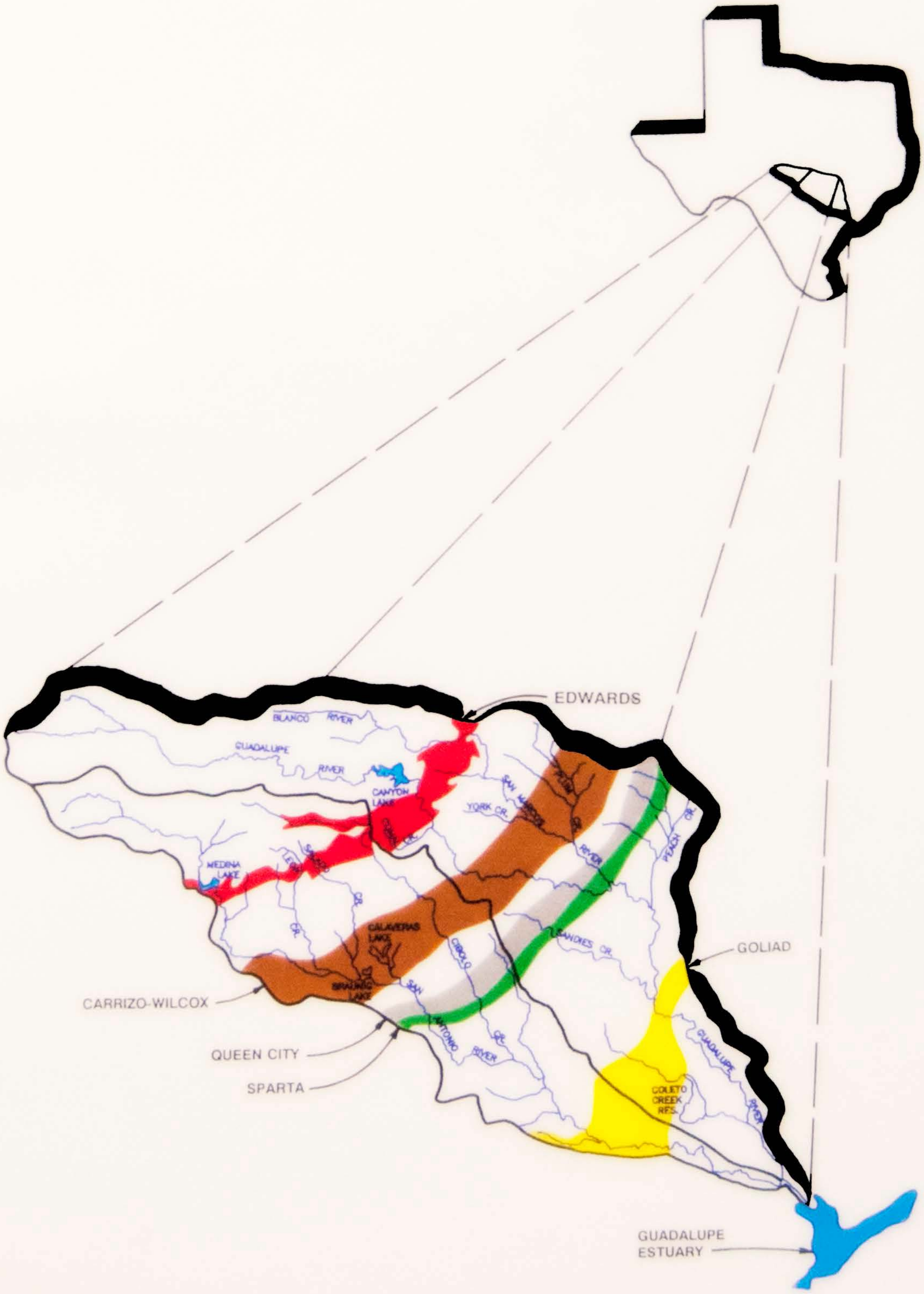
Recharge Enhancement Study

Guadalupe - San Antonio River Basin

Volume I - Executive Summary



Edwards Underground Water District

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HDR Engineering, Inc.
in association with
Espey, Huston & Assoc., Inc.

GUADALUPE - SAN ANTONIO RIVER BASIN

RECHARGE ENHANCEMENT STUDY

VOLUME I - EXECUTIVE SUMMARY

Prepared for

Edwards Underground Water District

by

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September, 1993

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Recharge Enhancement Study

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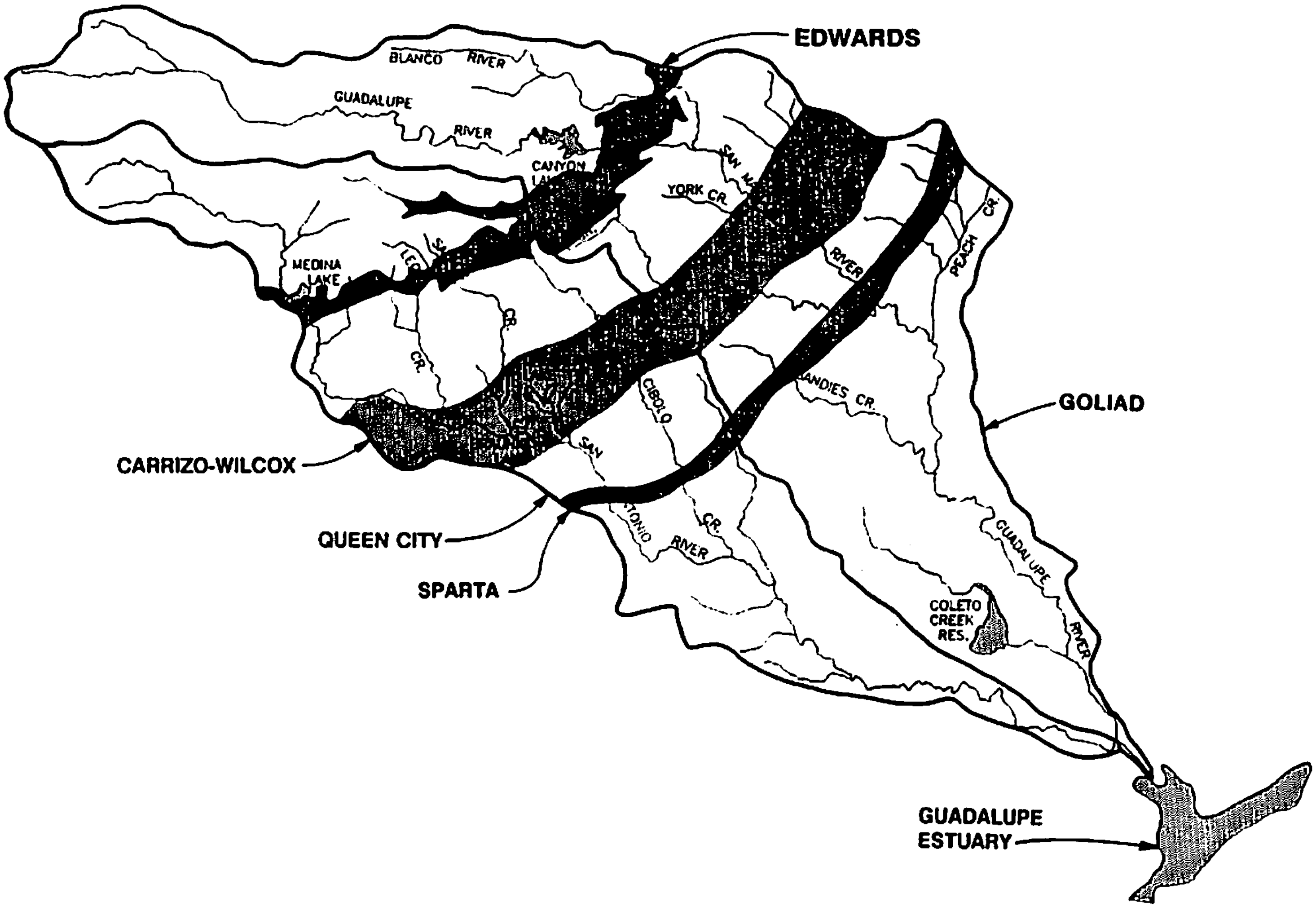
EXECUTIVE SUMMARY

GUADALUPE - SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

1. Study Background and Objectives

The Guadalupe - San Antonio River Basin encompasses over 10,100 square miles extending from the headwaters on the Edwards Plateau north and west of San Antonio through the Texas Blackland Prairie and Claypan Area, the Northern Rio Grande Plain, and the Gulf Coast Prairies to the Guadalupe Estuary south of Victoria. As is apparent in Figure ES1-1, the Guadalupe - San Antonio River Basin is crossed by at least five aquifer outcrops or recharge zones, including the Edwards, Carrizo-Wilcox, Queen City, Sparta, and Gulf Coast (Goliad). The most transmissive of these recharge zones is associated with the Edwards limestone aquifer and is generally located along the Balcones Escarpment. The Edwards Aquifer is presently the primary source of water supply for the City of San Antonio as well as numerous other cities and agricultural interests throughout Uvalde, Medina, Bexar, Comal, and Hays Counties. The aquifer also feeds Leona, San Pedro, San Antonio, Comal, and San Marcos Springs, creating unique environments and recreational opportunities while providing base flow to the Nueces, Leona, San Antonio, Guadalupe, and San Marcos Rivers.

The present and future economic dependence of entities currently served by the Edwards Aquifer and the flows emanating from its springs has prompted the Edwards Underground Water District (EUWD) to sponsor this Guadalupe - San Antonio River Basin Recharge Enhancement Study. An Advisory Committee representative of the diverse interests potentially affected by enhancement of Edwards Aquifer recharge was assembled



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

STUDY AREA MAP

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FIGURE ES1-1

by the EUWD to provide guidance and technical review throughout the study effort.

The concept of recharge enhancement is not new. In 1964, the U. S. Army Corps of Engineers (USCE) published a report identifying a number of potential projects located near the Edwards Aquifer recharge zone intended to capture and recharge additional flood flows which would not have entered the aquifer naturally. Since that time, the EUWD has constructed projects on Seco, Parkers, Verde, and San Geronimo Creeks with the expressed purpose of recharge enhancement and has sponsored detailed studies of potential projects in the Nueces River Basin. Significant results and products of studies of the Nueces River Basin include new estimates of historical Edwards Aquifer recharge which differ from previous estimates and development of a new river basin model capable of calculating potential recharge enhancement while considering downstream water rights and estuarine inflows.

The key objectives of the Guadalupe - San Antonio River Basin Recharge Enhancement Study are summarized as follows:

- Development of new monthly estimates of historical Edwards Aquifer recharge consistent with those for the Nueces River Basin, thereby completing recharge estimates for the entire aquifer for the 1934-89 historical period.
- Development of a river basin computer model capable of evaluating recharge enhancement projects and water availability subject to variable water rights constraints and springflows.
- Calculation of maximum enhanced recharge potential and estuarine inflow reductions associated with a program of recharge projects subject to a range of springflow and water rights utilization scenarios.
- Calculation of maximum water potentially available at selected locations subject to a range of springflow and water rights utilization scenarios.

2. Development of Guadalupe - San Antonio River Basin Model

The development of the Guadalupe - San Antonio River Basin (GSA) Model included building selected features into a computer code to accomplish the following tasks:

- Estimation of natural and enhanced Edwards Aquifer recharge;
- Simulation of the operations of existing and proposed reservoirs subject to various Edwards Aquifer pumpage/springflow and surface water rights scenarios; and
- Calculation of water potentially available at selected locations subject to various Edwards Aquifer pumpage/springflow and surface water rights scenarios.

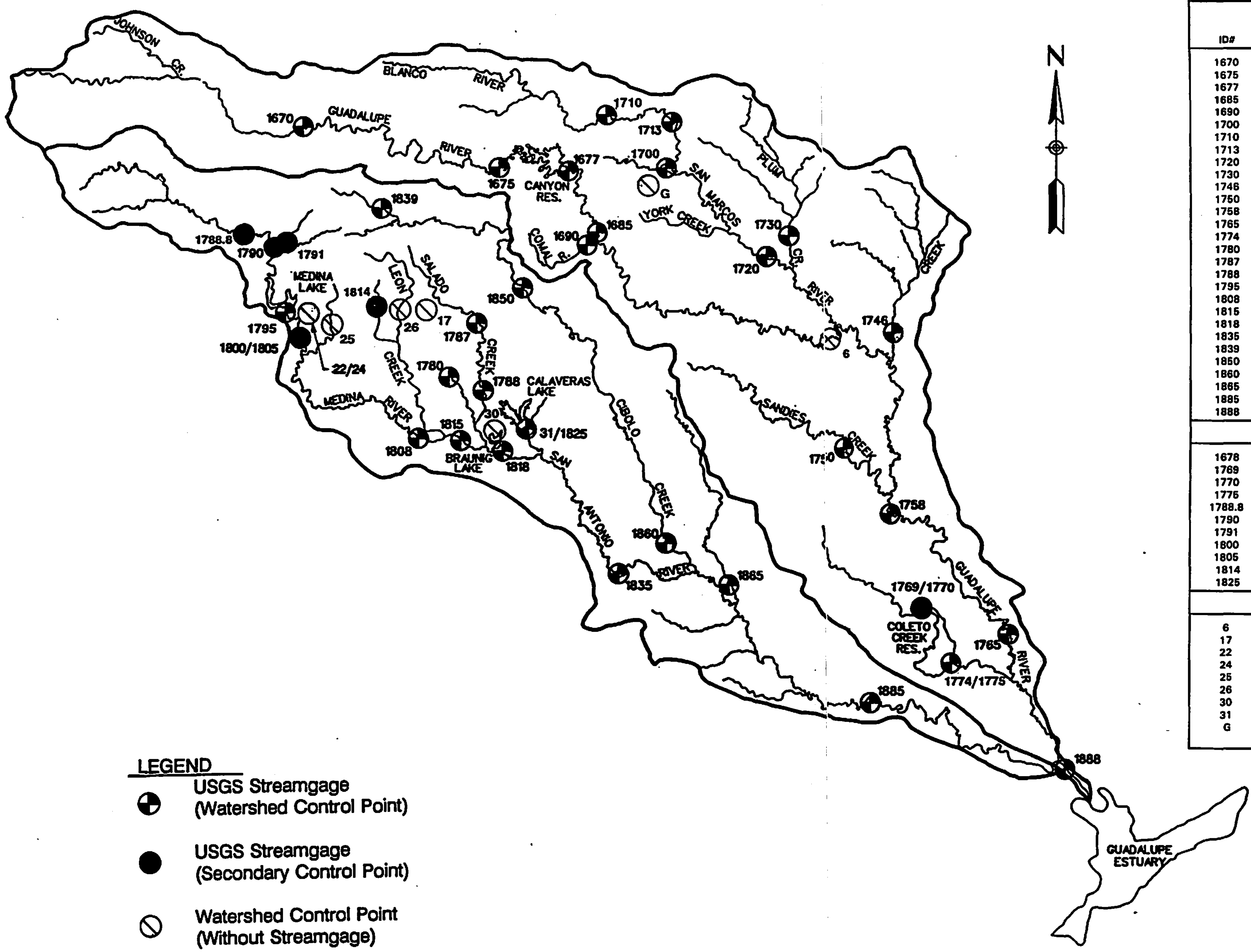
The computer model structure is based on the physical characteristics, water rights, and hydrologic phenomena which exist within the basin. Monthly computations simulating the movement of water throughout the basin proceed in an upstream to downstream fashion. The GSA Model was completed in two primary stages, which included the development of input databases, and a complete computer program code, followed by a series of tests for verification.

The input databases for the GSA Model include monthly natural streamflows and net evaporation sets, reservoir elevation-area-capacity tables, total water rights and utilizaton factors, return flows, channel loss rate function coefficients, and various control parameters which describe the basin configuration and control the operations of reservoirs and river diversions. Sources of information used in developing the input database for the GSA Model are summarized in Table ES2-1. Additional capabilities of the GSA Model include consideration of instream flow requirements and the import or export of water.

Figure ES2-1 identifies the USGS streamgages and other selected control points used to develop natural streamflows and channel loss rate functions for the 38 primary watershed

Table ES2-1
Hydrologic Data Sources

Data	Source
Streamflow	U.S. Geological Survey
Springflow	U.S. Geological Survey Texas Water Development Board
Reservoir Contents	U.S. Geological Survey Edwards Underground Water District City of San Antonio City Public Service
Precipitation	National Weather Service Texas Water Development Board U.S. Geological Survey
Evaporation	Texas Water Development Board
Well Levels	Edwards Underground Water District
Water Rights	Texas Water Commission Guadalupe-Blanco River Authority Espey, Huston & Associates, Inc.
Water Use	Texas Water Commission City Public Service
Return Flows	Texas Water Commission C. Thomas Koch, Inc.
Channel / Water Delivery Losses	U.S. Geological Survey
Reservoir Capacity	U.S. Army Corps of Engineers Soil Conservation Service Texas Water Development Board Freese & Nichols, Inc. Espey, Huston & Associates, Inc.



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- USGS Streamgage (Watershed Control Point)
- USGS Streamgage (Secondary Control Point)
- Watershed Control Point (Without Streamgage)

ID#	STREAM NAME, LOCATION	DRAINAGE AREA (SQ.MI.)	PERIOD OF RECORD
STREAMGAGES USED AS WATERSHED CONTROL POINTS			
1670	GUADALUPE R., COMFORT	839	6/39-12/89
1675	GUADALUPE R., SPRING BRANCH	1315	7/22-12/89
1677	CANYON LAKE	1432	7/62-12/89
1685	GUADALUPE R., ABOVE COMAL R.	1518	1/28-12/89
1690	COMAL R., NEW BRAUNFELS	130	1/28-12/89
1700	SAN MARCOS SPR., SAN MARCOS	N/A	6/56-12/89
1710	BLANCO R., WIMBERLEY	355	7/28-12/89
1713	BLANCO R., KYLE	412	6/56-12/89
1720	SAN MARCOS R., LULING	838	5/39-12/89
1730	PLUM C., LULING	309	4/30-12/89
1746	PEACH C., DILWORTH	460	8/59-9/79
1750	SANDIES C., WESTHOFF	549	8/59-12/89
1758	GUADALUPE R., CUERO	4934	9/20-11/35, 1/64-12/89
1765	GUADALUPE R., VICTORIA	5198	12/34-12/89
1774	COLETO CREEK RESERVOIR	494	2/80-12/89
1780	SAN ANTONIO R., SAN ANTONIO	41.8	3/39-12/89
1787	SALADO C., SAN ANTONIO, UPPER	137	10/60-12/89
1788	SALADO C., SAN ANTONIO, LOWER	189	10/60-12/89
1795	MEDINA LAKE	634	4/13-12/89
1808	MEDINA R., SOMERSET	967	10/70-12/89
1815	MEDINA R., SAN ANTONIO	1317	8/39-12/89
1818	SAN ANTONIO R., ELMENDORF	1743	10/62-12/89
1835	SAN ANTONIO R., FALLS CITY	2113	5/25-12/89
1839	CIBOLO C., BOERNE	68.4	3/62-12/89
1850	CIBOLO C., SELMA	274	4/46-12/89
1860	CIBOLO C., FALLS CITY	827	10/30-12/89
1865	ECLETO C., RUNGE	239	4/62-12/89
1885	SAN ANTONIO R., GOLIAD	3921	3/39-12/89
1888	GUADALUPE R., TIVOLI	10128	9/65-12/89
STREAMGAGES USED AS SECONDARY CONTROL POINTS			
1678	GUADALUPE R., SATTLER	1436	3/60-12/89
1769	COLETO C., SCHROEDER	357	10/78-12/89
1770	COLETO C., SCHROEDER	369	10/52-9/79
1775	COLETO C., VICTORIA	514	7/39-9/64, 6/78-12/89
1788.8	MEDINA R., BANDERA	427	10/82-12/89
1790	MEDINA R., PIPE CREEK	474	10/22-6/35, 10/52-9/82
1791	RED BLUFF C., PIPE CREEK	56.3	4/56-11/81
1800	MEDINA CANAL	N/A	4/22-4/34, 7/57-12/89
1805	MEDINA R., RIOMEDINA	650	2/53-9/73
1814	HELOTES C., HELOTES	15	6/68-12/89
1825	CALAVERAS C., ELMENDORF	77.2	10/54-9/71
WATERSHED CONTROL POINTS WITHOUT STREAMGAGES			
6	LAKE WOOD (H-5)	2103	1/80-12/89
17	OLMOS C., EDWARDS	8.3	N/A
22	DIVERSION LAKE SUBWATERSHED	15.6	N/A
24	DEEP C., EDWARDS	13.1	N/A
25	SAN GERONIMO C., EDWARDS	58.3	N/A
26	LEON C., EDWARDS	99.7	N/A
30	BRAUNIG LAKE	9.4	2/63-12/89
31	CALAVERAS LAKE	65.0	1/71-12/89
G	SINK, PURGATORY, YORK, AND ALLIGATOR CREEKS	94.0	N/A

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GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

WATERSHED CONTROL POINT AND STREAMGAGE LOCATION MAP

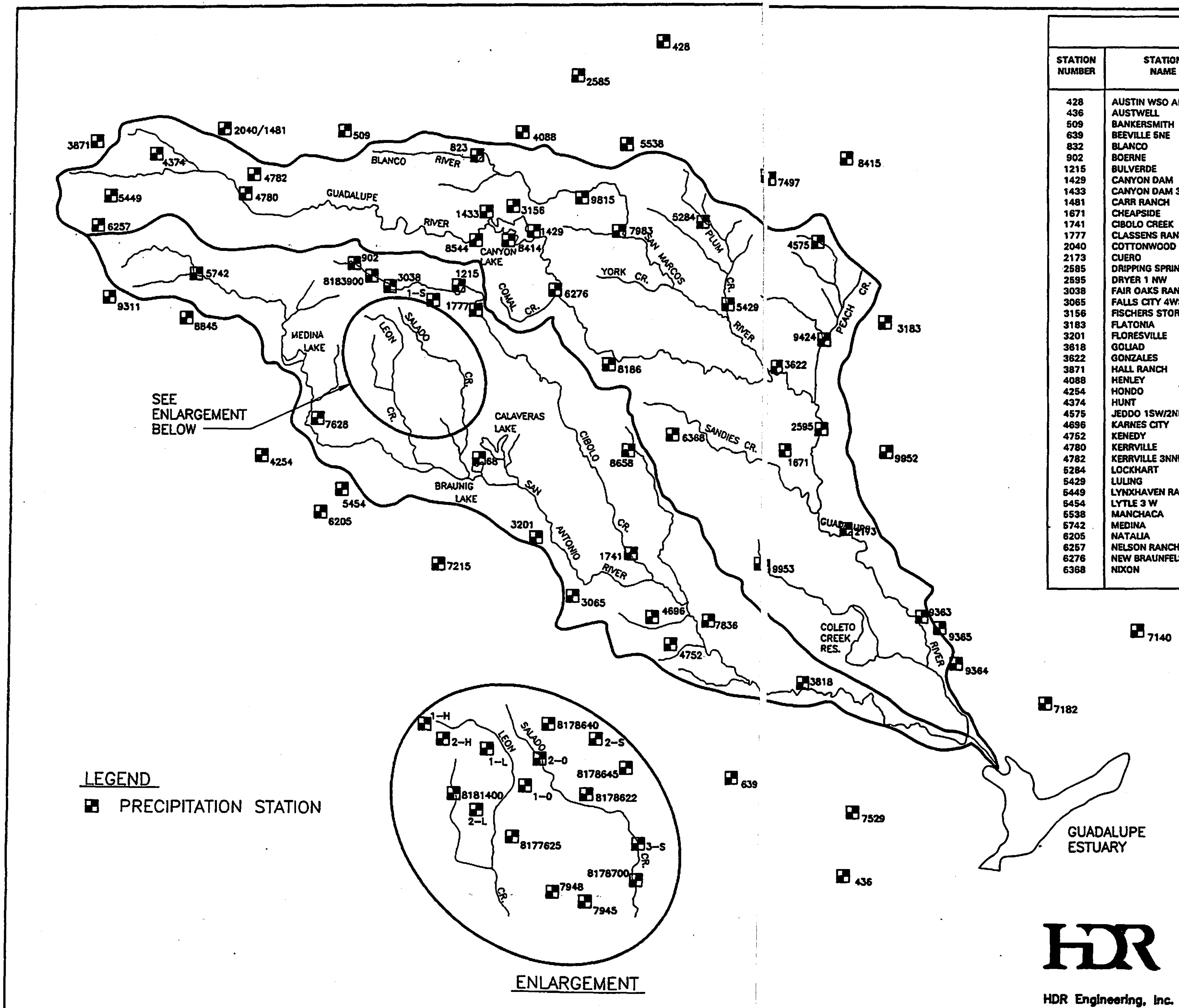
FIGURE ES2-1

control points used in the GSA Model. Natural streamflow is defined as that which would have occurred historically exclusive of human influences and is calculated by adjustment of gaged streamflows for the effects of historical water supply diversions, return flows, and reservoir operations.

Figure ES2-2 shows the locations of more than 80 precipitation stations used at various times throughout the study period in developing estimates of intervening runoff and net evaporation. Estimates of areal precipitation were used in the calculation of Edwards Aquifer recharge and the development of unique channel loss rate functions for each stream reach.

Figure ES2-3 shows those water rights in the Guadalupe - San Antonio River Basin having authorized annual diversion or storage rights in excess of 2,000 acre-feet. These diversion rights, along with all other municipal, industrial, irrigation, and mining water rights, were incorporated into the model in order to determine recharge enhancement potential and water potentially available at selected locations.

A unique aspect of the GSA Model is the incorporation of channel loss rates which were used in evaluating the impacts of upstream diversions and/or impoundments on flows at downstream locations. These loss rates were also used in simulating the delivery of releases from upstream reservoirs to downstream users. Channel loss rates were estimated for each stream segment from gaged upstream and downstream flows using calibrated estimates of intervening runoff with adjustments made for intervening diversions and return flows. Table ES2-2 illustrates that typical losses in the Guadalupe - San Antonio River Basin, though not as great as those observed in the Nueces River Basin, can be significant. Channel loss rates actually vary from month to month depending on how different



GUADALUPE AND SAN ANTONIO RIVER BASINS PRECIPITATION STATIONS

STATION NUMBER	STATION NAME	PERIOD OF RECORD USED IN STUDY	STATION NUMBER	STATION NAME	PERIOD OF RECORD USED IN STUDY
428	AUSTIN WSO AP	1923-89	7140	POINT COMFORT	1957-89
436	AUSTWELL	1923-60	7182	PORT LAVACA #2	1940-88
509	BANKERSMITH	1940-89	7215	POTEET	1941-89
639	BEEVILLE 5NE	1923-89	7422	RANDOLPH FIELD	1941-89
832	BLANCO	1923-89	7497	RED ROCK	1965-89
902	BOERNE	1923-89	7529	REFUGIO	1948-85
1215	BULVERDE	1940-89	7628	RIOMEDINA 2N	1923-89
1429	CANYON DAM	1961-89	7706	ROCKSPRINGS	1932-86
1433	CANYON DAM 3	1961-89	7836	RUNGE	1923-89
1481	CARR RANCH	1923-61	7945	SAN ANTONIO WSFO	1947-89
1671	CHEAPSIDE	1940-89	7948	SAN ANTONIO NURSERY	1923-51
1741	CIBOLO CREEK	1948-82	7983	SAN MARCOS	1923-89
1777	CLASSENS RANCH	1947-72	8186	SEGUIN	1923-72
2040	COTTONWOOD	1982-89	8414	SMITHSONS VALLEY	1947-55
2173	CUERO	1923-89	8415	SMITHVILLE	192J-89
2585	DRIPPING SPRINGS 6E	1984-89	8544	SPRING BRANCH	1956-89
2595	DRYER 1 NW	1940-75	8658	STOCKDALE 4N	1978-89
3038	FAIR OAKS RANCH	1947-73	8845	TARPLEY	1938-89
3065	FALLS CITY 4WSW	1946-89	9311	VANDERPOOL	1979-89
3156	FISCHERS STORE	1941-89	9363	VICTORIA WSO AP	1946-61
3183	FLATONIA	1923-89	9364	VICTORIA WB AP	1961-89
3201	FLORESVILLE	1923-89	9365	VICTORIA HWY 77 BR	1923-48
3618	GOLIAD	1923-89	9424	WAELDER 7SSW	1947-89
3622	GONZALES	1940-89	9815	WIMBERLEY 2	1984-89
3871	HALL RANCH	1940-76	9952	YOAKUM	1923-89
4088	HENLEY	1948-65	9953	YORKTOWN	1947-89
4254	HONDO	1923-75	68	BRAUNIG LAKE	1977-82
4374	HUNT	1947-89	8183900	CIBOLO CREEK	1988-89
4575	JEDDO 1SW/2NNE	1947-89	8178700	SALADO CREEK	1986-89
4696	KARNES CITY	1923-89	8177625	OLMOS CREEK	1987-89
4752	KENEDY	1949-77	8181400	HELOTES CREEK	1987-89
4780	KERRVILLE	1923-74	8185000	CIBOLO CREEK	1988-89
4782	KERRVILLE 3NNE	1974-89	8178645	EAST ELM CREEK	1987-89
5284	LOCKHART	1947-89	8178622	LORENCE CREEK	1988-89
5429	LULING	1923-89	8178640	WEST ELM CREEK	1987-89
5449	LYNXHAVEN RANCH	1951-76	1-H	HELOTES CREEK	1971-81
5454	LYTLE 3 W	1977-89	2-H	HELOTES CREEK	1971-81
5538	MANCHACA	1948-65	1-L	LEON CREEK	1971-81
5742	MEDINA	1986-89	2-L	LEON CREEK	1971-81
6205	NATALIA	1923-77	1-O	OLMOS CREEK	1971-81
6257	NELSON RANCH	1962-83	2-O	OLMOS CREEK	1971-81
6276	NEW BRAUNFELS	1923-89	1-S	SALADO CREEK	1971-81
6368	NIXON	1923-89	2-S	SALADO CREEK	1971-77
			3-S	SALADO CREEK	1971-81

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

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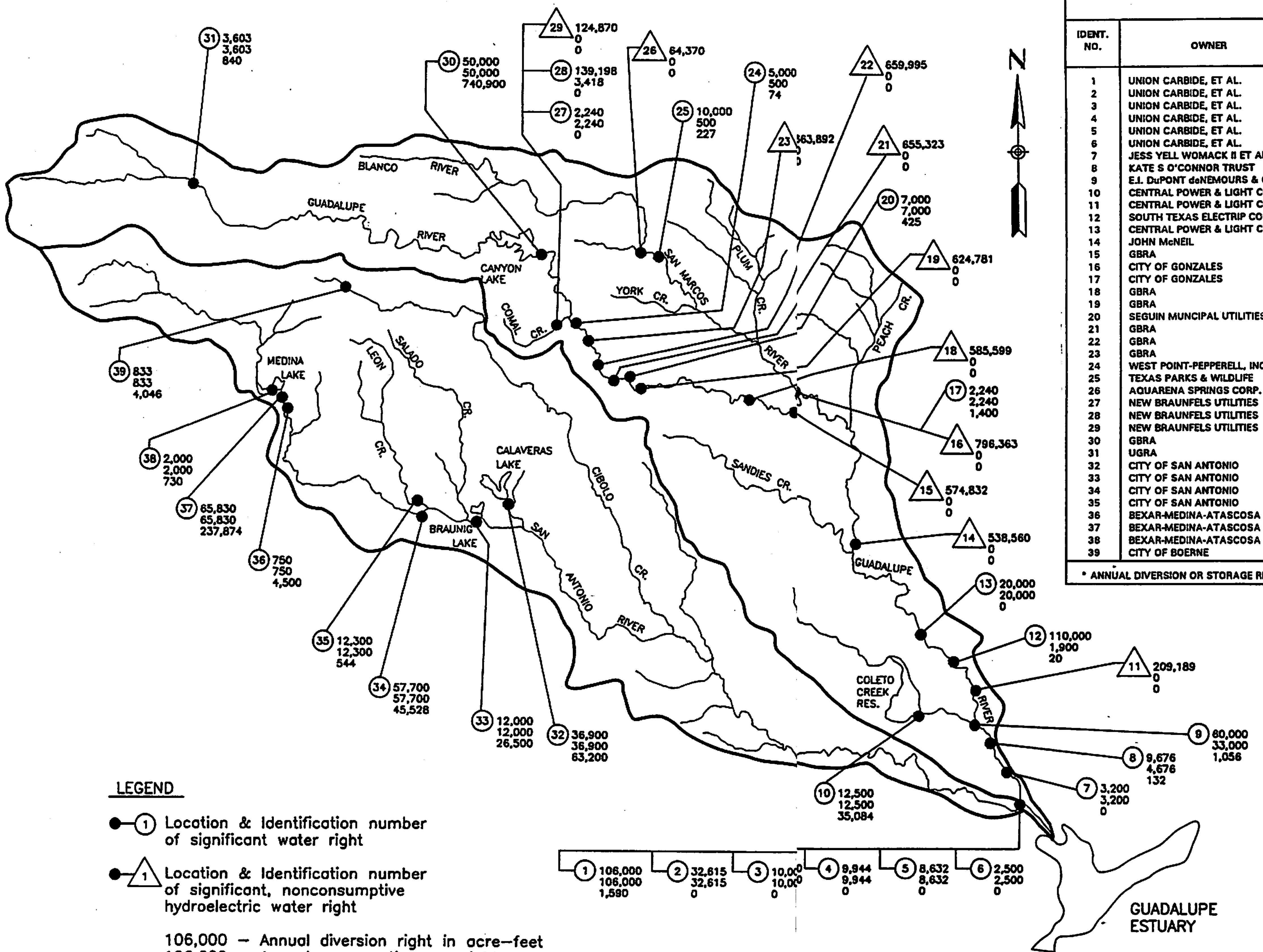
PRECIPITATION STATION LOCATION MAP

FIGURE ES2-2

SIGNIFICANT WATER RIGHTS*					
IDENT. NO.	OWNER	DIVERSION RIGHT (AC-FT/YR)	CONSUMPTIVE RIGHT (AC-FT/YR)	STORAGE RIGHTS (AC-FT/YR)	NOTES
1	UNION CARBIDE, ET AL.	106,000	106,000	1,590	
2	UNION CARBIDE, ET AL.	32,615	32,615	0	
3	UNION CARBIDE, ET AL.	10,000	10,000	0	
4	UNION CARBIDE, ET AL.	9,944	9,944	0	
5	UNION CARBIDE, ET AL.	8,632	8,632	0	
6	UNION CARBIDE, ET AL.	2,500	2,500	0	
7	JESS YELL WOMACK II ET AL.	3,200	3,200	0	
8	KATE S O'CONNOR TRUST	9,676	4,676	132	
9	E.I. DuPONT deNEMOURS & CO.	60,000	33,000	1,056	
10	CENTRAL POWER & LIGHT CO.	12,500	12,500	35,084	COLETO CREEK RES.
11	CENTRAL POWER & LIGHT CO.	209,189	0	0	
12	SOUTH TEXAS ELECTRIP COOP	110,000	1,900	20	
13	CENTRAL POWER & LIGHT CO.	20,000	20,000	0	
14	JOHN McNEIL	538,560	0	0	HYDROELECTRIC
15	GBRA	574,832	0	0	HYDROELECTRIC, H-5
16	CITY OF GONZALES	796,363	0	0	HYDROELECTRIC
17	CITY OF GONZALES	2,240	2,240	1,400	
18	GBRA	585,599	0	0	HYDROELECTRIC, H-4
19	GBRA	624,781	0	0	HYDROELECTRIC, TP-5
20	SEGUIN MUNCIPAL UTILITIES	7,000	7,000	425	
21	GBRA	655,323	0	0	HYDROELECTRIC, TP-4
22	GBRA	659,995	0	0	HYDROELECTRIC, TP-3
23	GBRA	663,892	0	0	HYDROELECTRIC, TP-2
24	WEST POINT-PEPPERELL, INC.	5,000	500	74	
25	TEXAS PARKS & WILDLIFE	10,000	500	232	
26	AQUARENA SPRINGS CORP.	64,370	0	0	HYDROELECTRIC
27	NEW BRAUNFELS UTILITIES	2,240	2,240	0	
28	NEW BRAUNFELS UTILITIES	139,198	3,418	0	
29	NEW BRAUNFELS UTILITIES	124,870	0	0	HYDROELECTRIC
30	GBRA	50,000	50,000	740,900	CANYON LAKE
31	UGRA	3,603	3,603	840	
32	CITY OF SAN ANTONIO	36,900	36,900	63,200	CALAVERAS LAKE
33	CITY OF SAN ANTONIO	12,000	12,000	26,500	BRAUNIG LAKE
34	CITY OF SAN ANTONIO	57,700	57,700	45,528	APPLEWHITE RES.
35	CITY OF SAN ANTONIO	12,300	12,300	544	
36	BEXAR-MEDINA-ATASCOSA WCID	750	750	4,500	DIVERSION LAKE
37	BEXAR-MEDINA-ATASCOSA WCID	65,830	65,830	237,874	MEDINA LAKE
38	BEXAR-MEDINA-ATASCOSA WCID	2,000	2,000	730	
39	CITY OF BOERNE	833	833	4,046	

* ANNUAL DIVERSION OR STORAGE RIGHTS IN EXCESS OF 2,000 ACRE-FEET.



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Location & Identification number of significant water right

Location & Identification number of significant, nonconsumptive hydroelectric water right

106,000 – Annual diversion right in acre-feet
106,000 – Annual consumptive use right acre-feet
2,643 – Storage right in acre-feet

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

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SIGNIFICANT WATER RIGHTS LOCATION MAP

FIGURE ES2-3

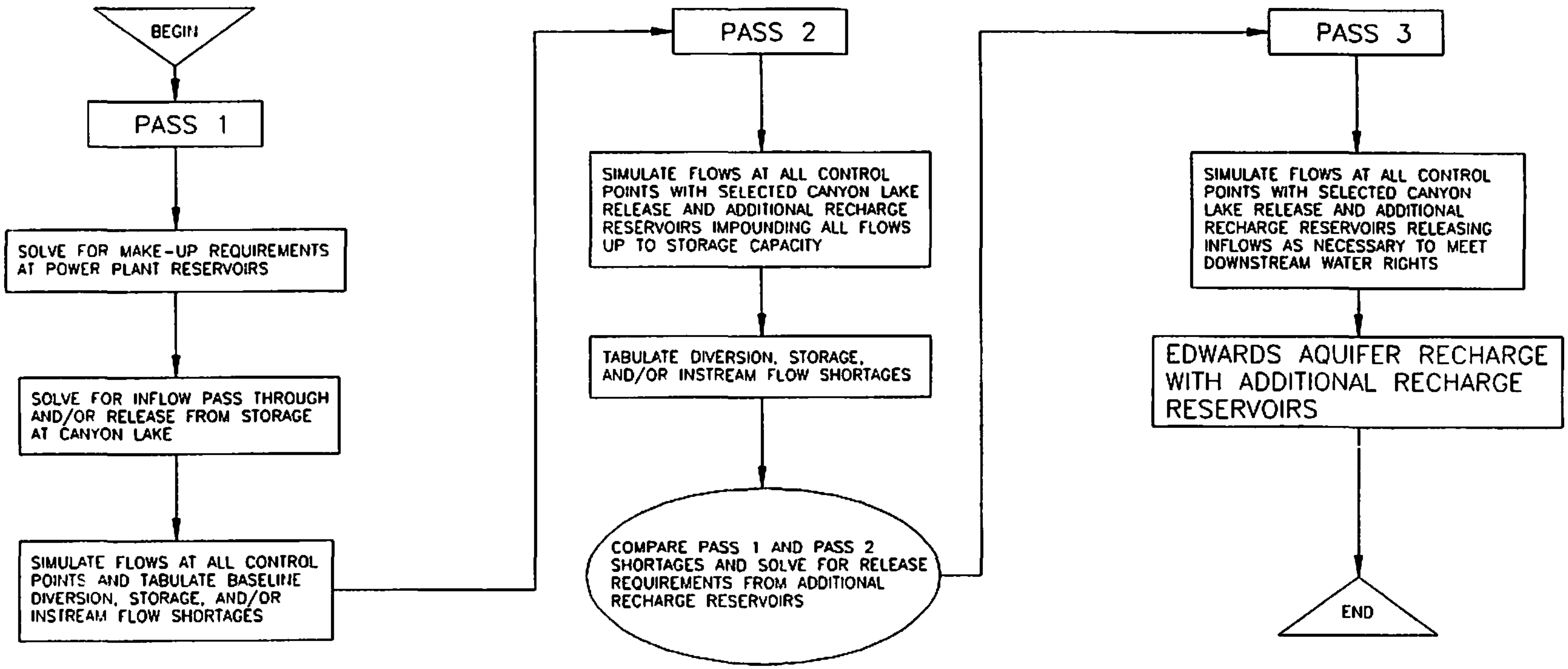
Table ES2-2 Examples of Channel Loss Rates	
River Reach	**Percentage of Upstream Flow Lost**
Guadalupe River at New Braunfels to Guadalupe River at Victoria	22%
Blanco River near Kyle to Guadalupe River at Victoria	22%
San Antonio River near Elmendorf to San Antonio River at Goliad	19%

assumptions in each model run (i.e, water rights use, return flows, new projects, etc.) affect the magnitude of upstream flow changes for each stream reach.

The program code for the GSA Model is in the FORTRAN programming language and is sufficiently generic that it can be compiled and executed on mainframe, micro, and many personal computers. The GSA Model uses a monthly time step proceeding with flow calculations in an upstream to downstream order simulating recharge, channel losses, water rights, return flows, and reservoir operations. Simulated reservoir operations include accounting for natural and imported inflows, net evaporation, leakage, recharge, releases, direct diversions, and spills in the calculation of end-of-month contents. For recharge reservoirs which are expected to retain water for less than a month after filling, net evaporation is not calculated. However, for recharge reservoirs and all other reservoirs which are expected to retain water for more than one month, net evaporation is included in the computations.

Verification of the GSA Model and the natural streamflow sequences was accomplished through reproduction of historical gaged flows and recharge estimates for each control point. More specifically, the GSA Model was verified by simulating the effects of historical diversions and return flows on the natural streamflows developed for each control point. The result of this simulation should be reproduction of the gaged streamflows and historical recharge estimates, if the model is functioning correctly. Agreement with the gaged flows and historical recharge estimates was virtually exact with some very minor discrepancies arising from the limited use of integer variables in the model.

A flowchart outlining the general computational steps used in the GSA Model is presented in Figure ES2-4. Computation of water available for recharge or other purposes at selected locations without adversely affecting downstream water rights is accomplished by the GSA Model using a three-pass process. In the first pass, operational releases from Canyon Lake (which may include both inflow pass through and release from storage) and make-up diversions for Coleto Creek, Braunig, and Calaveras Lakes are determined, flows are simulated at all control points, and any shortages (failures to satisfy diversion or storage rights) are tabulated. In the second pass, additional recharge projects are included, and shortages are tabulated for the entire river basin assuming full impoundment of inflows at the additional recharge project locations. In the third and final pass, the GSA Model solves for the portion of inflow at each additional recharge project which must be passed in order to satisfy all downstream water rights to the extent they were satisfied in the first pass. Any inflows which may be impounded without impacting downstream water rights are assumed to be available for recharge enhancement.



GUADALUPE-SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

RIVER BASIN MODEL FLOWCHART

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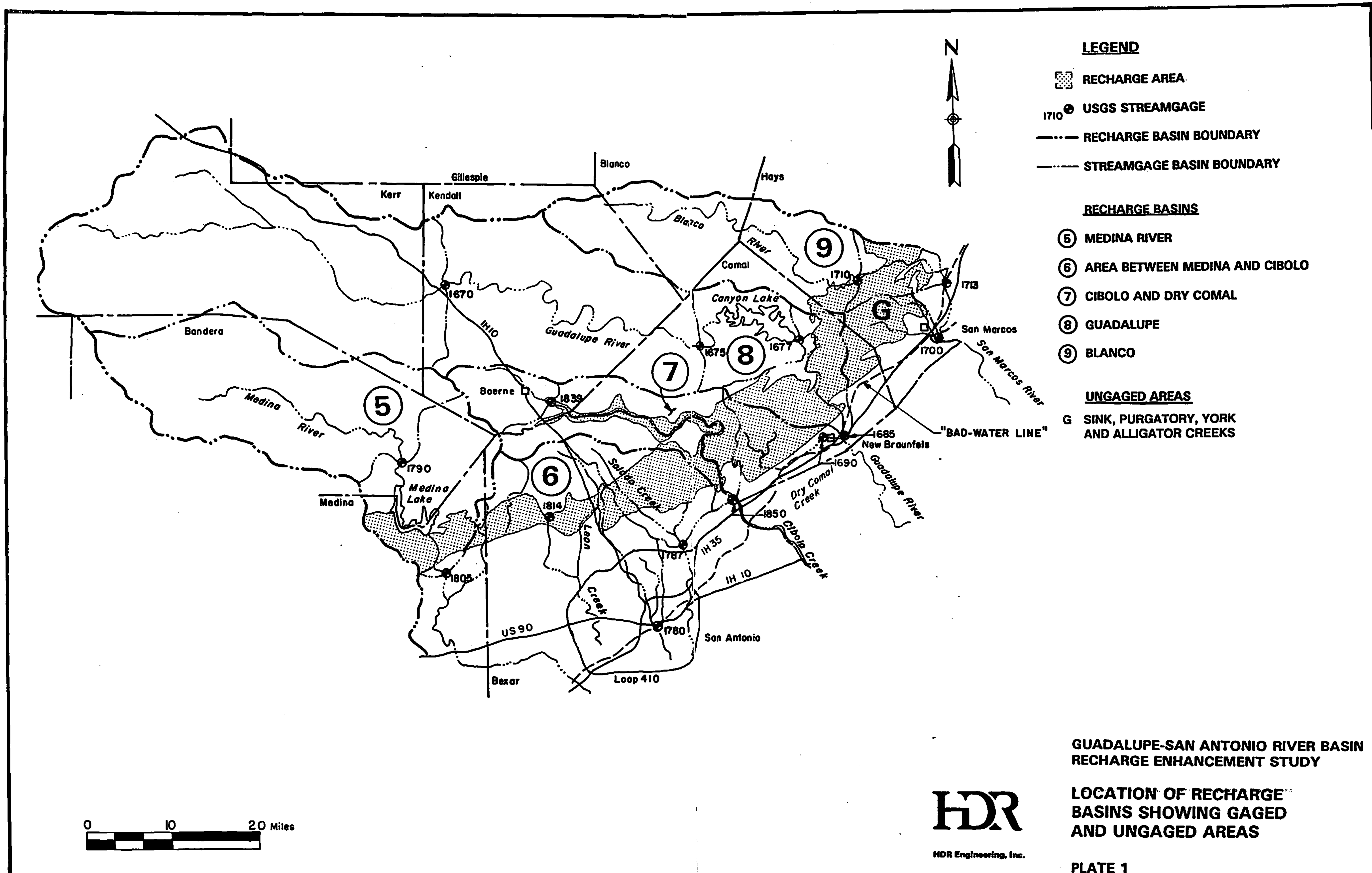
FIGURE ES2-4

3. Historical Recharge to the Edwards Aquifer

Historical average annual recharge to the Edwards Aquifer for the 1934 through 1989 period for each watershed within the Guadalupe - San Antonio River Basin was calculated and compared to the USGS recharge estimates for the same period. Plate 1 shows the watersheds which correspond to the recharge basins previously identified by the USGS. This comparison revealed that the previous USGS estimate of 270,000 ac-ft/yr is about 15 percent lower than the estimate of 316,000 ac-ft/yr computed by HDR. Although this difference in the long-term average is only marginally significant considering the complexity of the physical processes involved, important differences do exist in the geographical distribution of recharge among the various recharge basins.

Figure ES3-1 presents a comparison of the historical Edwards Aquifer recharge computed by the USGS and HDR for the Guadalupe - San Antonio River Basin and also for the Nueces River Basin, which was computed in a previous study (HDR, 1991). Table ES3-1 presents the geographical distribution of estimated recharge for the Nueces, San Antonio, and Guadalupe River Basins. In contrast to the Guadalupe - San Antonio River Basin, the recharge estimated by HDR for the Nueces River Basin proved to be consistently lower than the recharge reported by the USGS. In the westernmost watershed of the Guadalupe - San Antonio River Basin (Medina Lake), the recharge computed by HDR was lower than the USGS; however, in the eastern watersheds, the HDR recharge estimates were substantially higher than the USGS estimates.

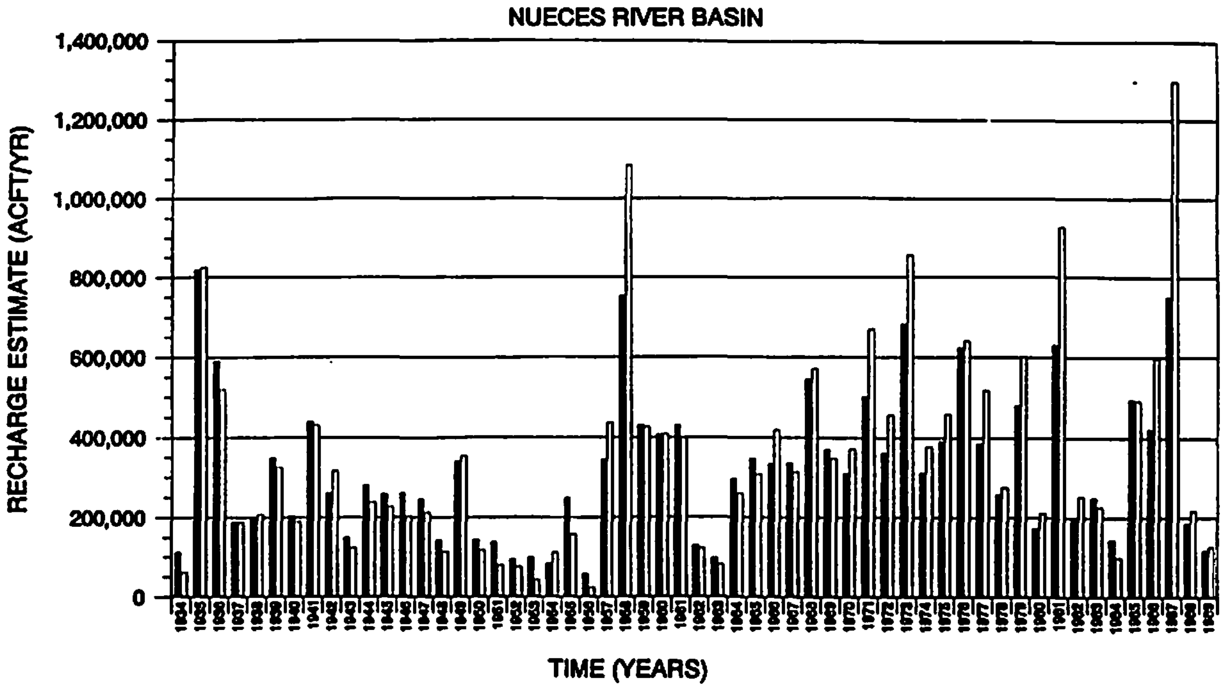
The modified geographical distribution of historical recharge reflected in the HDR estimates could have a significant effect on the calibration of existing Edwards Aquifer

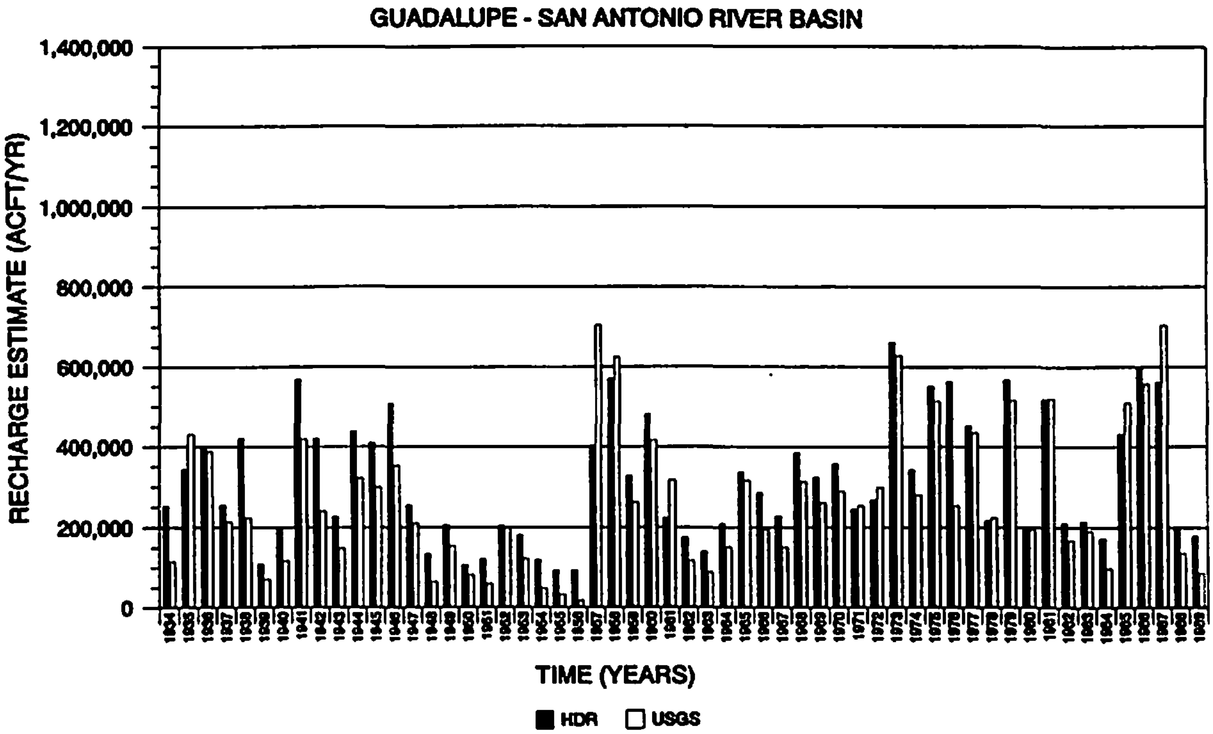


GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

LOCATION OF RECHARGE BASINS SHOWING GAGED AND UNGAGED AREAS

PLATE 1





GUADALUPE-SAN ANTONIO RIVER BASIN
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COMPARISON OF HISTORICAL EDWARDS AQUIFER RECHARGE BY RIVER BASIN

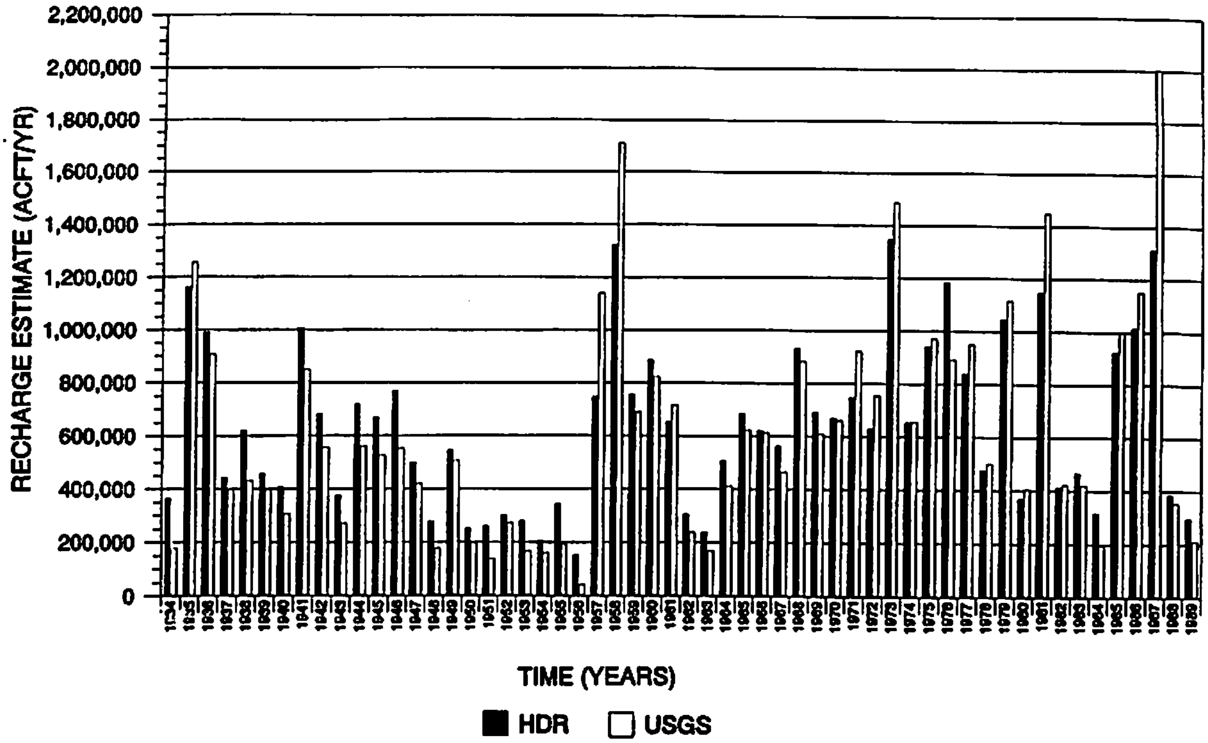
FIGURE ES3-1

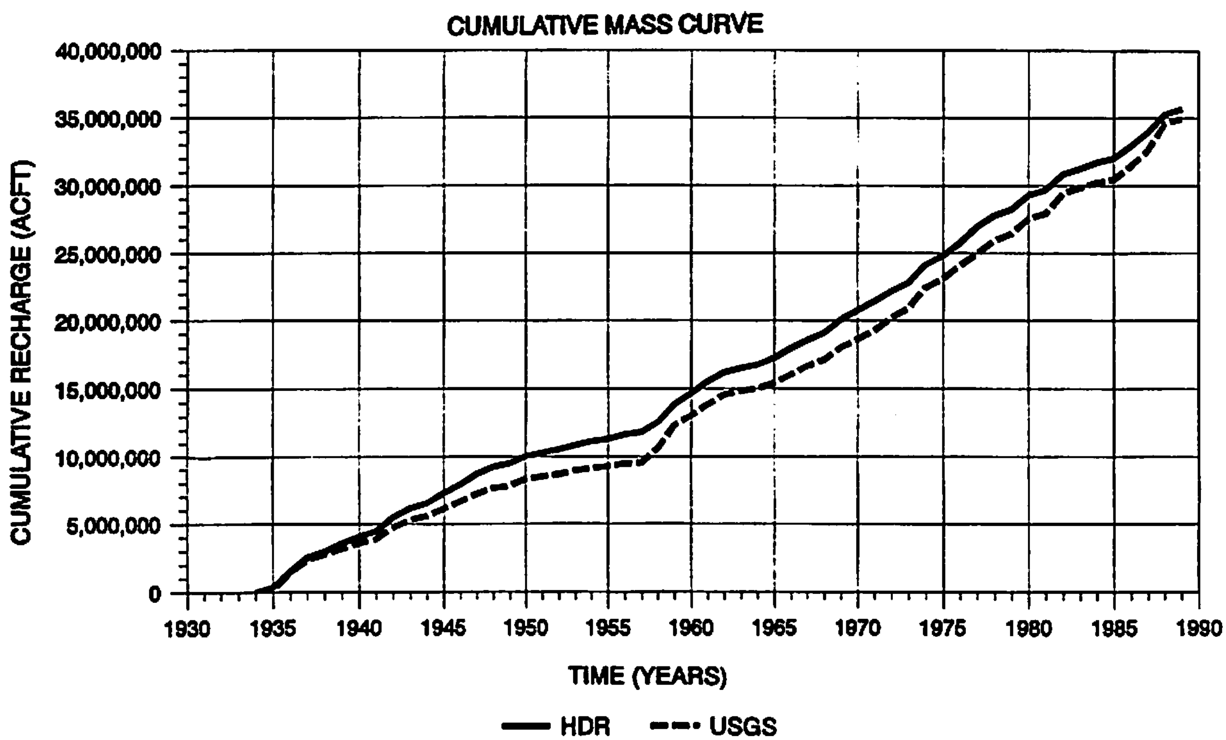
Table ES3-1
Comparison of Historical Edwards Aquifer Recharge by Basin

River Basin	Recharge Basin	HDR Recharge Estimate (Ac-Ft/Yr)	USGS Recharge Estimate (Ac-Ft/Yr)	Difference (Ac-Ft/Yr)	Percent Difference
Nueces	1. Nueces - W. Nueces	88,744	104,509	15,765	17.8%
	2. Frio - Dry Frio	111,739	117,454	5,715	5.1%
	3. Sabinal	32,581	38,307	5,726	17.6%
	4. Between Sabinal & Medina	92,998	97,404	4,406	4.7%
	SUBTOTAL	326,062	357,674	31,612	9.7%
San Antonio	5. Medina	41,833	60,780	18,947	45.3%
	6. Between Medina & Cibolo	88,274	67,705	-20,569	-23.3%
	7. Cibolo - Dry Comal	110,139	104,045	-6,094	-5.5%
	SUBTOTAL	240,246	232,530	-7,716	-3.2%
Guadalupe	8. Guadalupe	11,255	0	-11,255	-100.0%
	9. Blanco	64,523	37,758	-26,765	-41.5%
	SUBTOTAL	75,778	37,758	-38,020	-50.2%
	TOTAL	642,086	627,962	-14,124	-2.2%

models. The Texas Water Development Board (TWDB) used the HDR recharge estimates instead of the USGS estimates in various simulations to assess the effects these new recharge estimates might have on the predictive capability of the TWDB Edwards Aquifer Model. Preliminary comparisons of simulated versus actual Bexar County monitoring well (J-17) levels and San Marcos springflows obtained from the TWDB model using HDR recharge estimates generally show improved correlation as compared to simulations using the USGS recharge estimates. Additional improvement in simulated versus actual performance would be expected if the TWDB model were re-calibrated using the new recharge estimates.

Figure ES3-2 presents two comparisons of the total historical recharge to the Edwards Aquifer, including both the Nueces and Guadalupe - San Antonio River Basins. This comparison shows that the previous USGS estimate of 628,000 ac-ft/yr for the entire aquifer is





GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

COMPARISON OF HISTORICAL EDWARDS AQUIFER RECHARGE

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FIGURE ES3-2

about two percent lower than the estimate of 642,000 ac-ft/yr computed by HDR. However, for the individual watersheds in the eastern sections of the aquifer, the differences are much more significant, considering the proximity of these watersheds to Comal and San Marcos Springs, with the largest differences occuring in the Guadalupe and Blanco River Basins where the USGS recharge is 50 percent less than the HDR estimates.

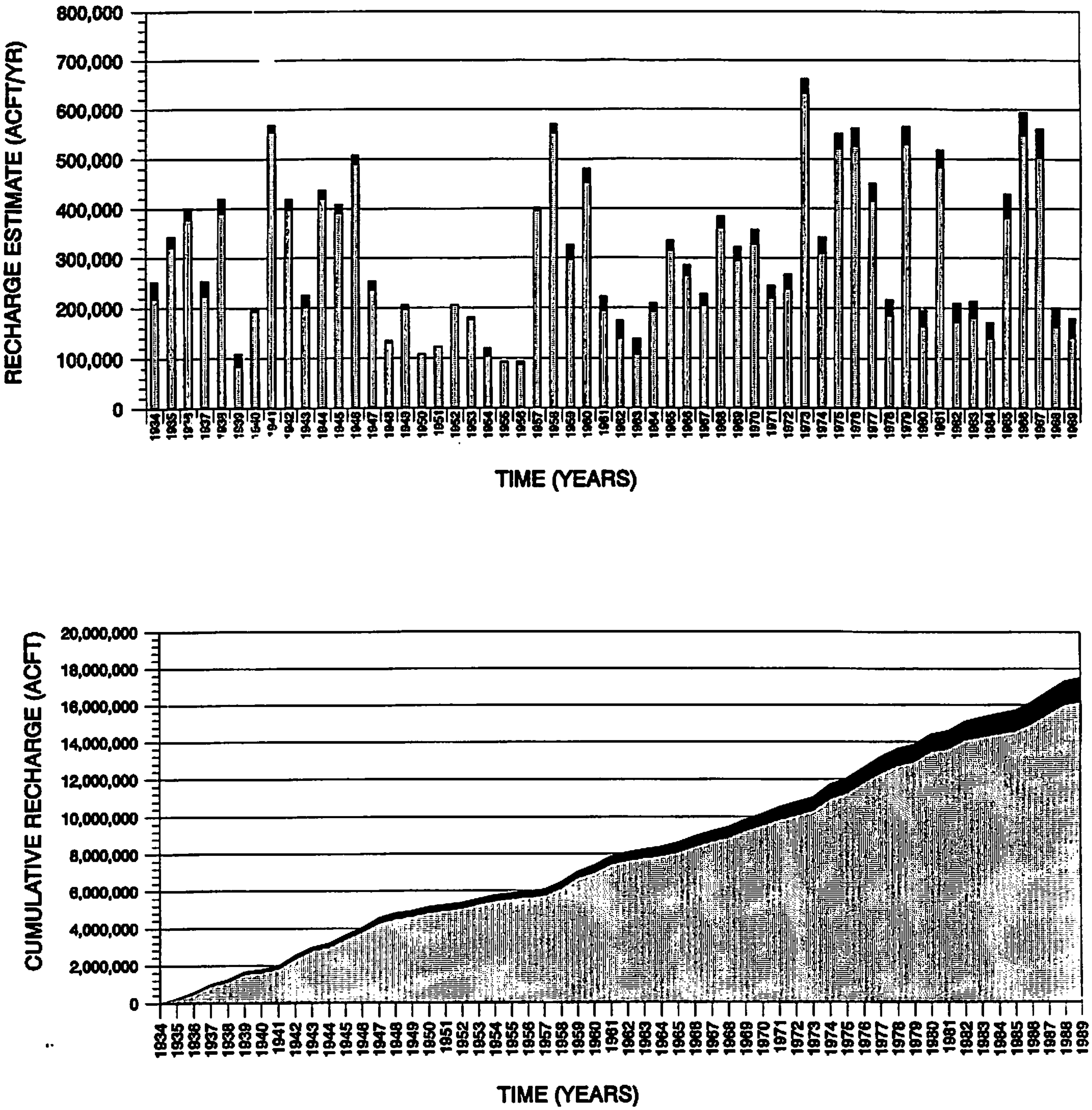
In order to understand the differences between the USGS and HDR estimates, key methodologies and assumptions must be considered. The principal difference between the HDR and USGS methods of calculating recharge is in estimating runoff directly over the recharge zone. Reasonable estimates of flow in this area are necessary to accurately calculate recharge. The method employed by the USGS assumes that runoff within the recharge zone is equal to the runoff from the area upstream of the recharge zone, adjusted for drainage area size and precipitation differences. The USGS assumes that runoff varies linearly with precipitation when adjusting for precipitation differences. The USGS method assumes that the runoff potential of the soil-cover complex is about the same in both the area upstream of and the area directly over the recharge zone. Procedures employed by HDR use a method based on Soil Conservation Service (SCS) procedures which takes into account differences in soil-cover complexes as well as differences in rainfall. Other differences between the HDR and USGS procedures include:

- HDR accounts for water rights diversions and return flows.
- HDR and USGS use different stage-recharge relationships for Medina Lake.
- HDR calculates recharge in the Guadalupe River Basin in the intervening area below Canyon Lake and above New Braunfels, including that occurring in the river channel when Edwards Aquifer levels are low. USGS does not calculate recharge in the Guadalupe River Basin.

- HDR and USGS select different partner watersheds for use in estimating the runoff potential for intervening areas on the recharge zone.

Overall, it appears that the HDR and USGS procedures produce similar recharge estimates in average years, while HDR estimates of recharge are higher in dry years and significantly lower in wet years.

Throughout the historical period, various reservoir structures have been constructed in the Guadalupe - San Antonio River Basin atop the Edwards Aquifer recharge zone which have enhanced the natural recharge to the aquifer. These structures include Medina Lake (constructed in 1911), San Geronimo Creek Recharge Dam, and various SCS Flood Retardation Structures (SCS/FRS) in the Salado Creek, Dry Comal Creek, and upper San Marcos River (including York Creek) watersheds. An estimate of natural recharge to the Edwards Aquifer in the Guadalupe - San Antonio River Basin was developed in order to approximate the effects of these structures. The average annual natural recharge in the Guadalupe River Basin is estimated to be 291,000 ac-ft as compared to the historical recharge (including existing structures) of 316,000 ac-ft, an 8.6 percent increase. Figure ES3-3 traces annual and cumulative historical recharge in the Guadalupe - San Antonio River Basin for the 1934 to 1989 period and identifies the portion attributable to the man-made structures in existence at the time.



NATURAL RECHARGE
HISTORICAL RECHARGE ENHANCEMENT

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

HDR Engineering, Inc.

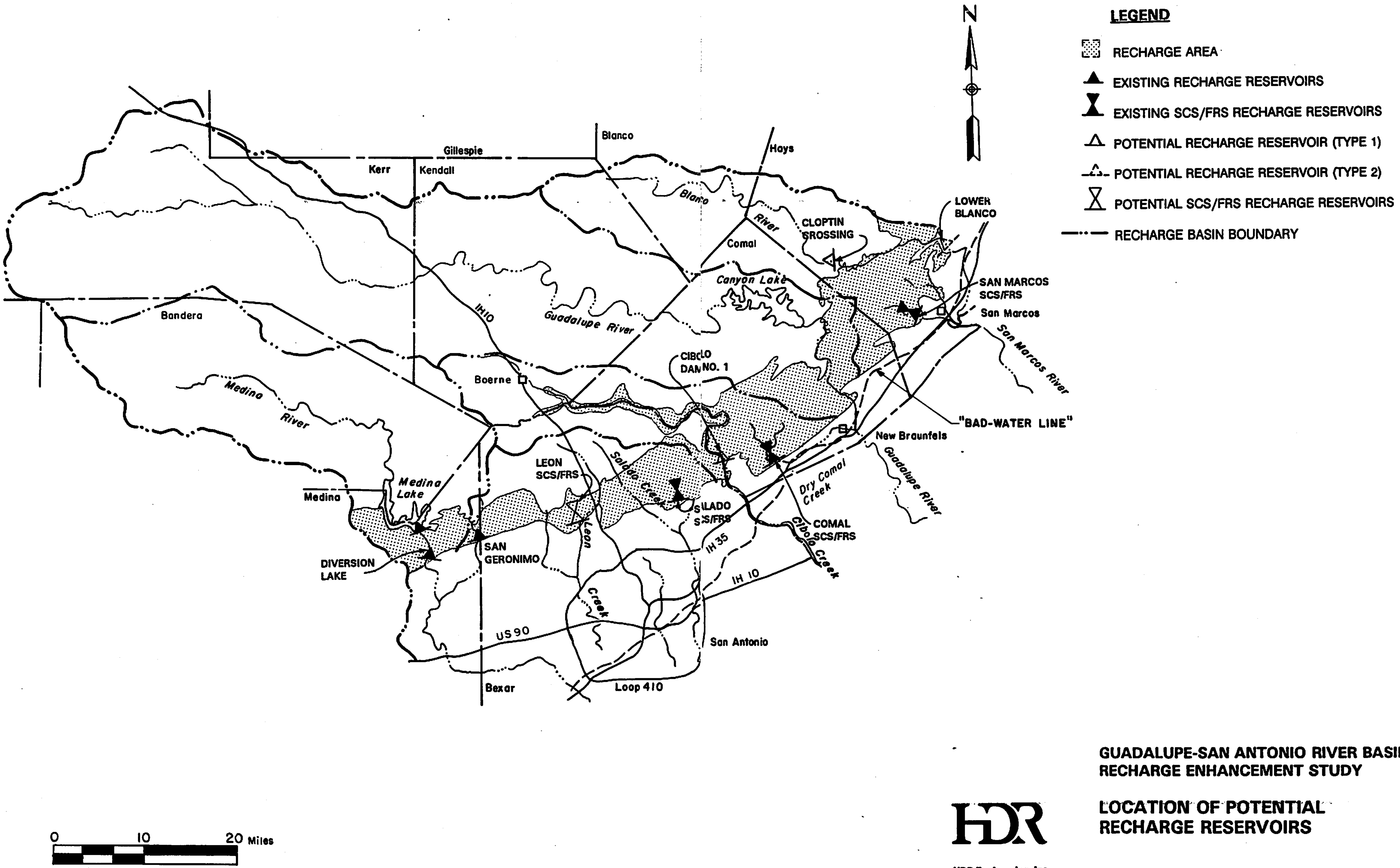
COMPARISON OF NATURAL AND HISTORICAL EDWARDS AQUIFER RECHARGE

FIGURE ES3-3

4. Potential Recharge Enhancement Projects

The approximate locations of all potential recharge reservoirs and existing reservoirs which contribute to the recharge of the Edwards Aquifer in the Guadalupe - San Antonio River Basin are shown in Plate 2. Although the Cloptin Crossing and Cibolo Dam No. 1 projects have been identified and examined in previous studies, other potential recharge reservoirs were generally sited without detailed consideration of economic, geologic, environmental, or other factors of human interest. The express purpose of the projects selected for analysis in this study is the determination of the theoretical maximum additional recharge attainable. The reader is cautioned that this study was performed to assess the potential for recharge enhancement in the Guadalupe - San Antonio River Basin subject to the current state of water supply development and without regard for proposed water resource developments or environmental needs. Any use of the results of this study should be appropriately qualified in accordance with the following abbreviated list of factors, each of which, when applied, may serve to reduce the amount of recharge enhancement potential reported herein:

- Smaller projects dictated by economics;
- Water requirements for more valuable supply alternatives;
- Water requirements for environmental needs;
- Reuse of treated wastewater effluent;
- Limited recharge enhancement during severe drought;
- Site geology and/or regional hydrogeology; and
- Location of recharge enhancement relative to demand centers and/or springs.



GUADALUPE-SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

LOCATION OF POTENTIAL RECHARGE RESERVOIRS

HDR

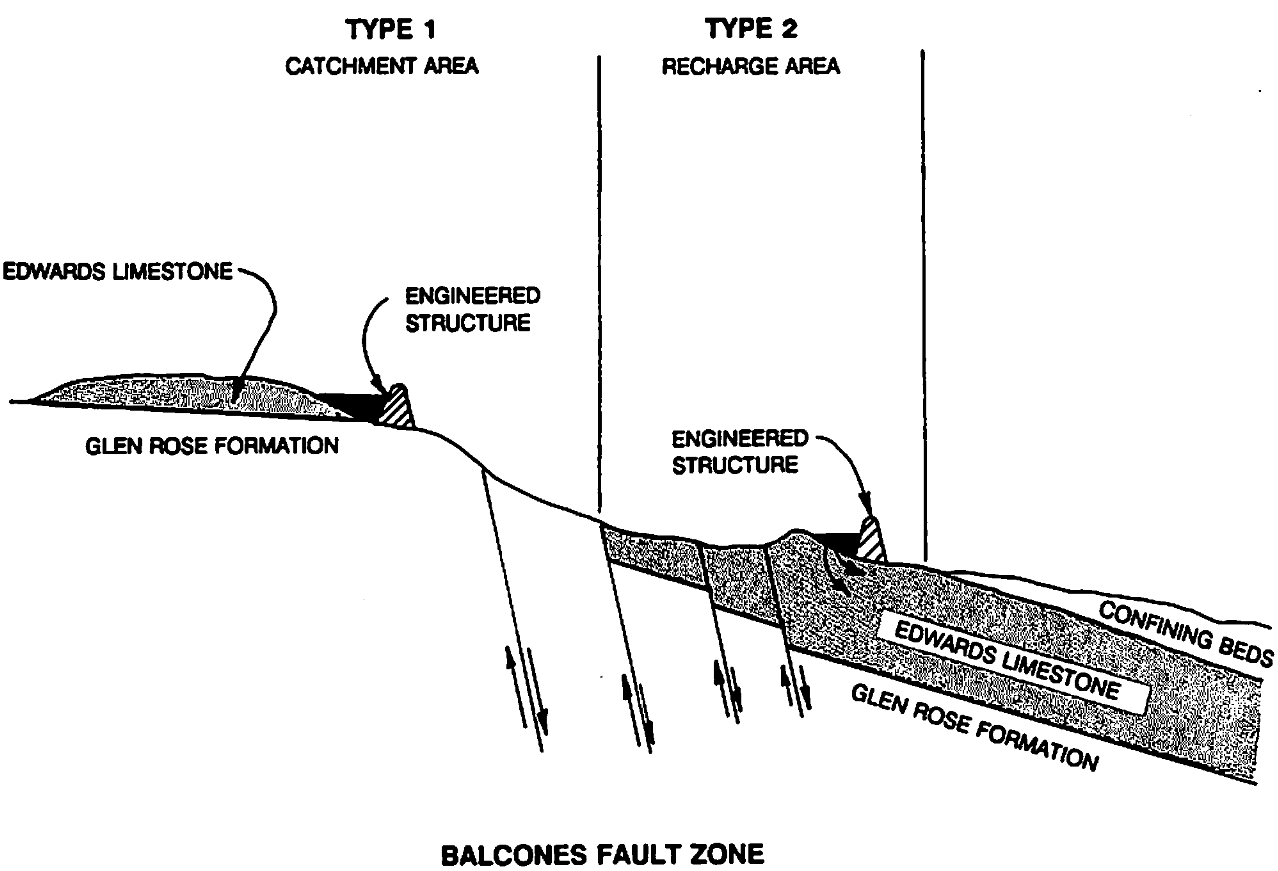
HDR Engineering, Inc.

PLATE 2

The effect of each of these factors on recharge enhancement potential may be measured in subsequent studies when suitable criteria for the application of each is established.

The two general types of recharge reservoirs are illustrated in Figure ES4-1. Type 1 or "catch and release" reservoirs are located upstream of the recharge zone and are operated to release water at the maximum recharge rate of the downstream channel. Carryover storage from one month to the next is frequent in Type 1 reservoirs so net evaporation losses are included in the simulation of reservoir contents. Cloptin Crossing Reservoir is the only Type 1 project considered in this study. Type 2 or "direct percolation" reservoirs are located within the recharge zone and recharge directly through the bottom of the reservoir with the entire volume usually draining within a period of less than one month. Normally, evaporation losses are not calculated for Type 2 reservoirs. Cibolo Dam No. 1 and Lower Blanco Reservoir are the only Type 2 projects considered individually in this study. Due to relatively low natural recharge rates along the Blanco River, direct diversions from either the Cloptin Crossing or Lower Blanco Reservoir for injection to the aquifer and/or transfer to the adjacent upper San Marcos River watershed were modelled in order to more efficiently recharge water impounded in these reservoirs. Since the Lower Blanco Reservoir will normally have carryover storage, net evaporation losses were calculated.

Existing Soil Conservation Service Flood Retardation Structure (SCS/FRS) projects exhibit characteristics of both Type 1 and Type 2 reservoirs in that both controlled releases and direct percolation serve to drain any storage which has been temporarily impounded. In this study, SCS/FRS reservoirs are grouped by watershed for calculation of recharge, and net evaporation losses are assumed negligible due to the rapid rate at which storage is



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

TYPES OF RECHARGE RESERVOIRS

HDR

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FIGURE ES4-1

typically evacuated from these reservoirs. Analyses of hydrologic data from the Salado Creek and Dry Comal Creek watersheds indicates that, on the average, approximately 100 percent and 70 percent of the water stored in the normal and active pools, respectively, contributes to recharge. If the recharge characteristics of the SCS/FRS were not incorporated in their original design, it is possible that restriction and/or closure of reservoir outlets could enhance recharge without adversely affecting the flood control function of these projects.

Potential recharge enhancement projects considered in this study have been generally classified and grouped into "Structural" and/or "Operational" programs. The various potential recharge enhancement projects have been classified and grouped in this way simply for organized presentation in this document. Projects classified as "Structural" involve the development of additional storage through new reservoir construction, while those classified as "Operational" may involve modification of existing structures, acquisition of existing water rights, or re-activation of a project found to be economically unfeasible. Structural recharge enhancement projects analyzed include the following:

- Enlargement of the existing San Geronimo Creek Recharge Dam and/or development of additional storage upstream.

- Development of a program of small SCS/FRS in the Leon, Helotes, and Government Creek watersheds similar to that in the Salado Creek watershed.

- Cibolo Dam No. 1 on Cibolo Creek near Selma.

- One additional SCS/FRS in the Dry Comal Creek watershed.

- Lower Blanco project on the Blanco River near Kyle.

Operational recharge enhancement projects analyzed include the following:

- Acquisition of irrigation rights at Medina and Diversion Lakes for diversion and injection to the Edwards Aquifer.
- Modification or closure of SCS/FRS outlets in the Salado Creek, Dry Comal Creek, and upper San Marcos River watersheds.
- Cloptin Crossing project on the Blanco River near Wimberley.

Potential recharge enhancement with the Structural Program in place has been calculated subject to two water rights and three Edwards Aquifer pumpage/springflow scenarios. The two water rights scenarios include full utilization of permitted water rights and reported utilization for 1988. Simulations under the Full Water Rights Scenario are based on the following assumptions:

- All rights and contracts divert full authorized amounts.
- Permitted annual diversions and contractual obligations from Canyon Lake total 50,000 ac-ft.
- Flow requirement of 600 cfs at Lake Dunlap for hydroelectric power generation.
- Annual consumptive use (forced evaporation) at Braunig, Calaveras, and Coleto Creek Lakes based on estimated full potential power generation.
- Return flows in each stream segment equal to those reported for 1988.

Simulations under the 1988 Water Usage Scenario are based on the following assumptions:

- All rights and contracts divert amounts reported for 1988. Diversion and storage rights associated with Applewhite Reservoir and the Leon Creek Diversion are excluded from this scenario.
- Permitted annual diversions and contractual obligations from Canyon Lake total 50,000 ac-ft.

- Flow requirement of 0 cfs at Lake Dunlap assuming full subordination of hydroelectric power generation.

- Annual consumptive use (forced evaporation) at Braunig, Calaveras, and Coleto Creek Lakes equal to that reported for 1988.

- Return flows in each stream segment equal to those reported for 1988.

The three Edwards Aquifer pumpage/springflow scenarios considered in this study assumed fixed annual use of water directly from the aquifer totalling 250,000 ac-ft, 400,000 ac-ft, or 450,000 ac-ft. With the assistance of the TWDB, monthly springflow sequences were calculated for Comal, San Marcos, San Antonio, and San Pedro Springs utilizing their model of the Edwards Aquifer. The TWDB modified the Edwards Aquifer model in order to include HDR estimates of historical recharge in both the Nueces and Guadalupe - San Antonio River Basins and to estimate aquifer discharge to the Guadalupe River near Hueco Springs.

The results of recharge enhancement calculations for the Structural Program are summarized in Tables ES4-1 and ES4-2 for long-term average and drought conditions, respectively. Long-term average (1934-89) Guadalupe - San Antonio River Basin recharge enhancement due to the listed new reservoirs totalled approximately 48,300 ac-ft/yr (an increase of 15.1 percent over the historical recharge) and 51,200 ac-ft/yr (an increase of 15.9 percent over the historical recharge) under the Full Water Rights and 1988 Water Usage Scenarios, respectively. Drought average (1947-56) recharge enhancement due to the listed new reservoirs totalled approximately 24,000 ac-ft/yr (an increase of 15.7 percent over the historical recharge) under the Full Water Rights Scenario and 25,000 ac-ft/yr (an increase of 16.1 percent over the historical recharge) under the 1988 Water Usage Scenarios. As is apparent in Tables ES4-1 and ES4-2, recharge enhancement with new structures is not very

Table ES4-1
Recharge Enhancement with Structural Program for Average Conditions (1934-89)

Recharge Basin	New Reservoirs	Maximum Storage (Ac-Ft)	Historical[1] Average Annual Recharge (Ac-Ft/Yr)		Recharge Enhancement With Structural Program (Ac-Ft/Yr)[3] Pumpage Scenario 1 250,000 Ac-Ft/Yr		Pumpage Scenario 2 400,000 Ac-Ft/Yr		Pumpage Scenario 3 450,000 Ac-Ft/Yr	
			Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage
5) Medina River			40,610	42,250						
6) Area between Medina River and Cibolo Creek			85,550	85,550						
	San Geronimo	3,500			1,715	3,550	1,715	3,550	1,715	3,550
	Leon Creek FRS[2]	25,200			5,230	6,120	5,205	6,120	5,205	6,120
7) Cibolo Creek and Dry Comal Creek			113,965	114,300						
	Cibolo Dam	10,000			8,485	8,520	8,485	8,520	8,485	8,520
	Dry Comal FRS	2,075			1,335	1,335	1,335	1,335	1,335	1,335
8) Guadalupe River			11,255	11,255						
9) Blanco River			68,135	68,295						
	Lower Blanco	35,230			31,610	31,715	31,515	31,650	31,495	31,640
Recharge Enhancement (Ac-Ft/Yr)[3]					48,375	51,240	48,255	51,175	48,235	51,165
Total Recharge (Ac-Ft/Yr)			319,515	321,650	367,890	372,890	367,770	372,825	367,750	372,815
Percent Increase in Historical[1] Recharge					15.1%	15.9%	15.1%	15.9%	15.1%	15.9%
Total Spring Flow (Ac-Ft/Yr)			340,850		382,815		264,925		226,960	

Notes: 1) Historical Recharge is adjusted for existing structures and includes Medina Lake, San Geronimo Dam, and SCS/FRS programs in place for the entire period.
2) Leon Creek FRS includes an SCS/FRS program in the Leon Creek, Helotes Creek, and Government Creek watersheds.
3) Development of these projects will likely require compromises in size, location, mitigation of wildlife habitat, and other factors which may reduce the actual recharge enhancement attainable relative to the theoretical amounts reported herein.

Table ES4-2
Recharge Enhancement with Structural Program for Drought Conditions (1947-56)

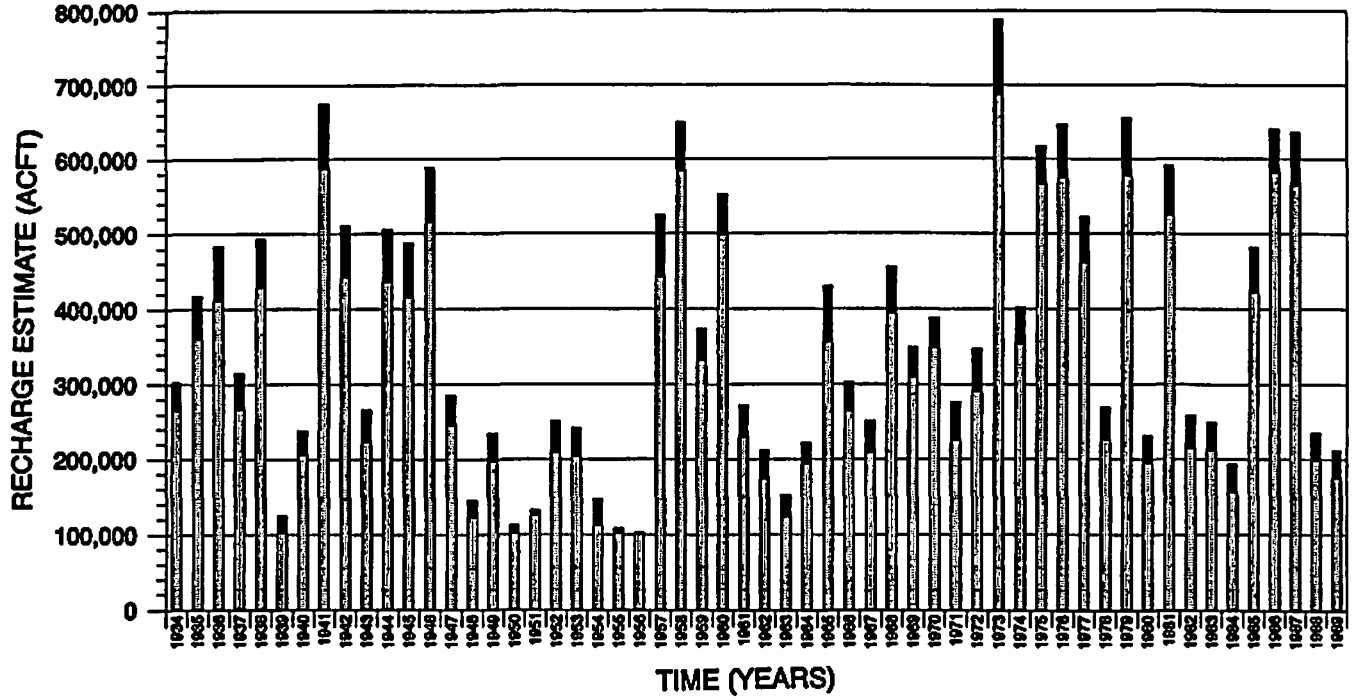
Recharge Basin	New Reservoirs	Maximum Storage (Ac-Ft)	Historical[1] Average Annual Recharge (Ac-Ft/Yr)		Recharge Enhancement With Structural Programs (Ac-Ft/Yr)[3]					
					Pumpage Scenario 1 250,000 Ac-Ft/Yr		Pumpage Scenario 2 400,000 Ac-Ft/Yr		Pumpage Scenario 3 450,000 Ac-Ft/Yr	
			Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage
5) Medina River			11,755	12,370						
6) Area between Medina River and Cibolo Creek			33,705	33,705						
	San Geronimo	3,500			560	785	560	785	560	785
	Leon Creek FRS[2]	25,200			1,950	2,395	1,815	2,395	1,815	2,395
7) Cibolo Creek and Dry Comal Creek			52,735	52,990						
	Cibolo Dam	10,000			1,265	1,265	1,265	1,265	1,265	1,265
	Dry Comal FRS	2,075			520	525	520	525	520	525
8) Guadalupe River			17,595	17,595						
9) Blanco River	Lower Blanco	35,230	37,355	37,725	19,850	20,105	19,515	19,850	19,465	19,835
Recharge Enhancement (Ac-Ft/Yr)[3]					24,145	25,075	23,675	24,820	23,625	24,805
Total Recharge (Ac-Ft/Yr)			153,145	154,385	177,290	179,460	176,820	179,205	176,770	179,190
Percent Increase in Historical[1] Recharge					15.8%	16.2%	15.5%	16.1%	15.4%	16.1%
Total Springflow (Ac-Ft/Yr)			230,970		203,800		96,980		66,425	

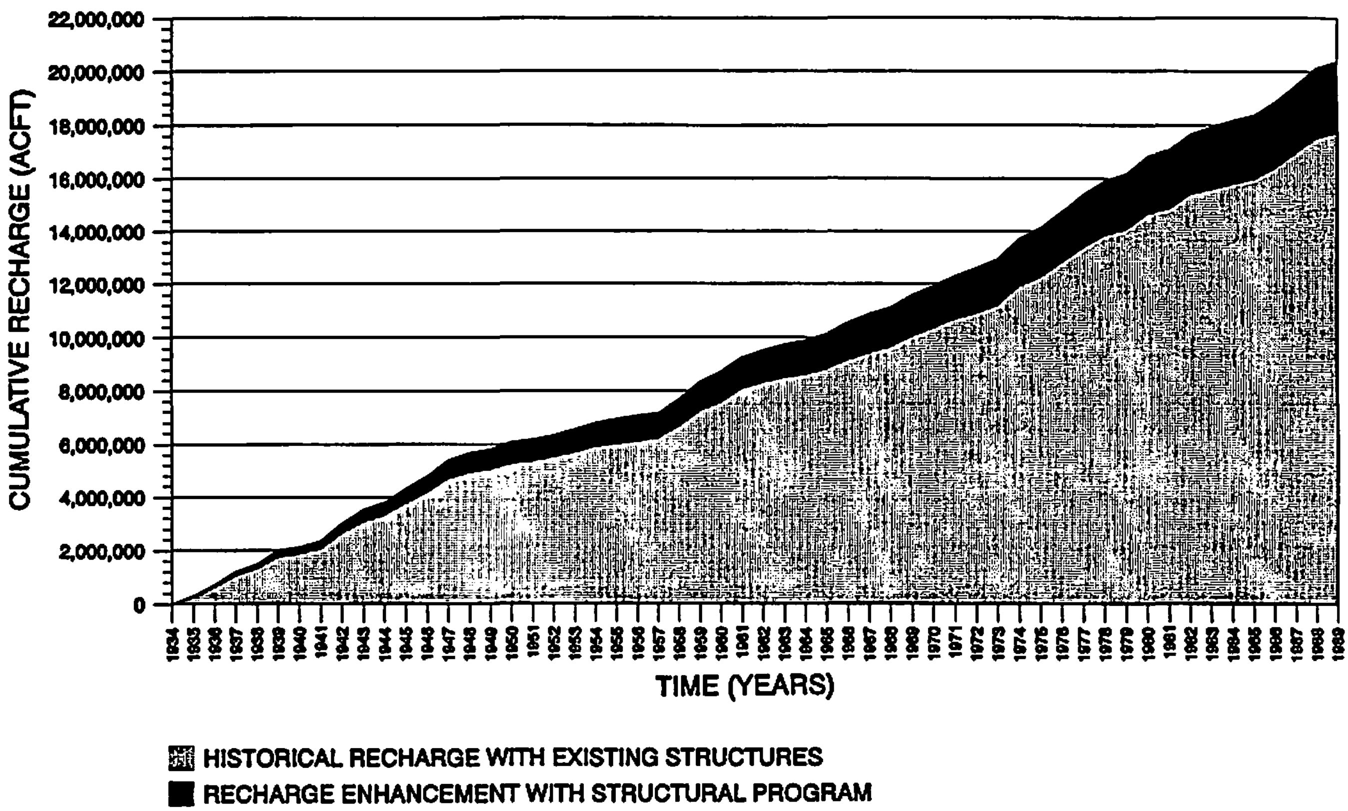
Notes: 1) Historical Recharge is adjusted for existing structures and includes Medina Lake, San Geronimo Dam, and SCS/FRS programs in place for the entire period.
2) Leon Creek FRS includes an SCS/FRS program in the Leon Creek, Helotes Creek, and Government Creek watersheds.
3) Development of these projects will likely require compromises in size, location, mitigation of wildlife habitat, and other factors which may reduce the actual recharge enhancement attainable relative to the theoretical amounts reported herein.

sensitive to either the assumed Edwards Aquifer pumpage/springflow scenario (with minor exceptions) or to the degree of water rights utilization. Figure ES4-2 presents annual and cumulative recharge of the Edwards Aquifer in the Guadalupe - San Antonio River Basin for the 1934-89 period, illustrating the relative magnitudes of baseline historical recharge with existing structures and enhanced recharge with the Structural Program subject to the Full Water Rights Scenario. Figure ES4-3 provides a similar illustration focusing on annual recharge estimates during the 1947-56 drought period.

It is interesting to note that about 65 percent of the potential additional recharge under average conditions and over 80 percent of the potential additional recharge under drought conditions is a result of the Lower Blanco Reservoir. This reservoir is the largest among the group of projects classified as structural with an assumed maximum storage volume of 35,230 ac-ft. Due to the limited recharge rates observed in this portion of the Blanco River, net evaporation losses were considered, and direct diversions to the upper San Marcos River watershed for injection or natural recharge were assumed, in order to obtain the full recharge enhancement potential at this site. The Lower Blanco Reservoir is also quite efficient with respect to minimization of losses to evaporation. The free water surface area exposed to evaporative losses at maximum storage for this project is one-third less than that for the same storage volume at the upstream Cloptin Crossing site.

Tables ES4-1 and ES4-2 also reveal the significant differences in recharge enhancement potential in the San Geronimo and Leon Creek watersheds subject to each water rights scenario. Long-term average combined recharge enhancement in these two watersheds totals about 6,920 ac-ft/yr (an increase of 8.1 percent over the historical recharge) under the Full Water Rights Scenario and 9,670 ac-ft/yr (an increase of 11.3 percent over the historical recharge) under the





NOTES: PUMPAGE SCENARIO 3: 450,000 ACFT/YR
FULL WATER RIGHTS SCENARIO

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

STRUCTURAL PROGRAM
RECHARGE ENHANCEMENT

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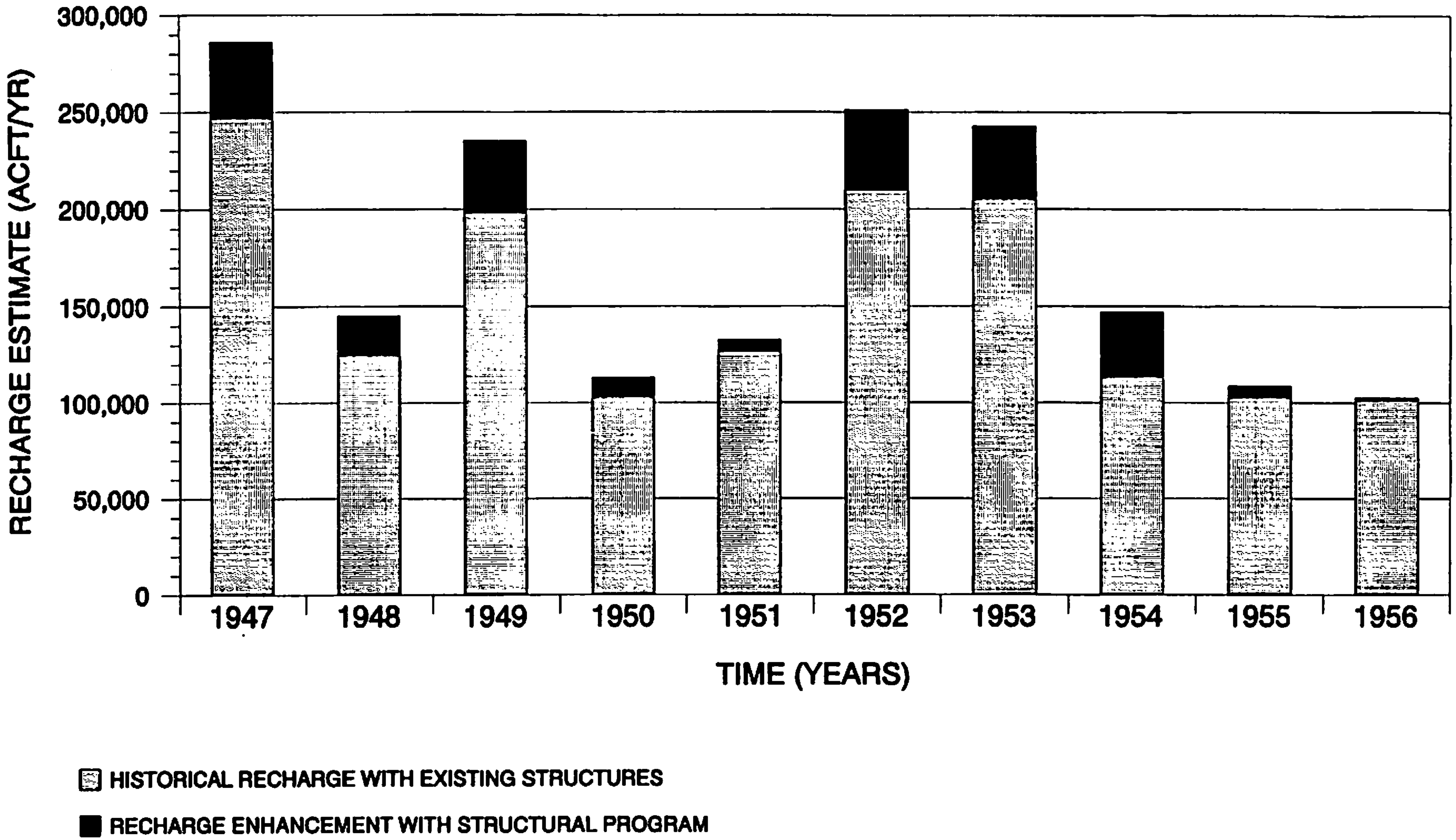
FIGURE ES4-2



NOTES: PUMPAGE SCENARIO 3: 450,000 ACFT/YR
FULL WATER RIGHTS SCENARIO

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GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

STRUCTURAL PROGRAM DROUGHT RECHARGE ENHANCEMENT

FIGURE ES4-3

1988 Water Usage Scenario. This difference of 2,730 ac-ft/yr in recharge enhancement is a result of the exclusion of Applewhite Reservoir and the Leon Creek Diversion from the 1988 Water Usage Scenario.

Potential recharge enhancement with the Operational Program added to the Structural Program was calculated subject to the Full Water Rights Scenario previously described and springflows resulting from a fixed annual pumpage of 450,000 ac-ft from the Edwards Aquifer. Simulations for the Operational Program include all projects from the Structural Program except the Lower Blanco Reservoir which would not likely be feasible in conjunction with the Cloptin Crossing project. Long-term average (1934-89) Guadalupe - San Antonio River Basin recharge enhancement under the Operational Program totalled approximately 123,060 ac-ft/yr (an increase of 38.5 percent over the historical recharge) and drought average (1947-56) recharge enhancement totalled approximately 66,300 ac-ft/yr (an increase of 43.3 percent over the historical recharge). Table ES4-3 provides a side-by-side comparison of potential recharge enhancement in each recharge basin for the Structural and combined programs.

An average of approximately 55,395 ac-ft/yr (45.0 percent of the long-term average recharge enhancement under the operational program) could be available for diversion and injection to the Edwards Aquifer by acquisition of Medina and Diversion Lake irrigation rights totalling 67,830 ac-ft/yr. Such diversions were assumed to be accomplished on a monthly schedule similar to that for irrigation use so that historical recharge estimates for Medina and Diversion Lakes would be unaffected. It is noted that water available for diversion under these rights would be severely limited during drought due to depletion of storage in Medina Lake. Although recharge enhancement averaged 20,935 ac-ft/yr during the 1947-56 drought period, water available during the 1954-56 period averaged only 3,735 ac-ft/yr.

Table ES4-3
Recharge Enhancement with Structural and Operational Programs

Recharge Basin	Operational Projects	Historical[1] Recharge (Ac-Ft/Yr)		Recharge Enhancement (Ac-Ft/Yr)[2,5]			
				Structural Program		Structural and Operational Programs[3]	
		Average (1934-89)	Drought (1947-56)	Average (1934-89)	Drought (1947-56)	Average (1934-56)	Drought (1947-56)
5) Medina River		40,610	11,755				
	Irrigation Purchase					55,395	20,935
6) Area between Medina River and Cibolo Creek		85,550	33,705	6,920	2,375	6,920	2,375
	Salado Creek FRS					485	0
7) Cibolo Creek and Dry Comal Creek		113,965	52,735	9,820	1,785	9,820	1,785
	Dry Comal FRS					1,145	390
8) Guadalupe River		11,255	17,595				
9) Blanco River		68,135	37,355	31,495	19,465		
	Cloptin Crossing					48,275	40,690
	San Marcos FRS					1,020	125
Recharge Enhancement (Ac-Ft/Yr)[5]				48,235	23,625	123,060	66,300
Total Recharge (Ac-Ft/Yr)		319,515	153,145	367,750	176,770	442,575	219,445
Percent Increase in Historical[1] Recharge				15.1%	15.4%	38.5%	43.3%
Estuarine Inflow (Ac-Ft/Yr) and Percent Reduction		1,548,395	514,065	-2.0%	-2.7%	-3.4%	-3.2%

Notes:
1) Historical Recharge is adjusted for existing structures and includes Medina Lake, San Geronimo Dam, and SCS/FRS programs in place for the entire period.
2) Recharge Enhancement based on Pumpage Scenario 3 (450,000 Ac-Ft/Yr) and Full Water Rights Scenario.
3) Includes all projects from the Structural Program except Lower Blanco Reservoir.
4) Estuarine inflows and percent reductions are based on flows at the Saltwater Barrier near Tivoli subject to Pumpage Scenario 3 (450,000 ac/ft-yr).
5) Development of these projects will likely require compromises in size, location, mitigation of wildlife habitat, and other factors which may reduce the actual recharge enhancement attainable relative to the theoretical amounts reported herein.

The Cloptin Crossing Reservoir project was found to be economically unfeasible by the U.S. Army Corps of Engineers in 1979 and was placed in a deferred category. Simulations indicate, however, that it could provide significant recharge enhancement in both average times and during severe drought periods. Comparing the Cloptin Crossing Reservoir with the previously discussed Lower Blanco Reservoir reveals that the Cloptin Crossing Reservoir could provide 53 percent and 109 percent more recharge enhancement under average and drought conditions, respectively. However, the conservation storage of Cloptin Crossing Reservoir is eight times that of the Lower Blanco Reservoir and the assumed diversion rate from Cloptin Crossing for injection to the Edwards Aquifer was more than four times that assumed for the Lower Blanco Reservoir. More detailed economic and hydrologic analyses will be necessary to evaluate the relative merits of these alternative projects.

As indicated in Table ES4-3, an additional measure of recharge enhancement could be obtained through closure of SCS/FRS outlets in the watersheds where SCS/FRS programs are in place. It is estimated that, on the average, the existing SCS/FRS programs increase recharge in the Guadalupe - San Antonio River Basin by 12,760 ac-ft/yr (4.0 percent) over that which would occur naturally. Closure of SCS/FRS outlets in the Salado Creek, Dry Comal Creek (including the outlet of the additional SCS/FRS included in the Structural Program), and upper San Marcos River watersheds could contribute an additional 2,650 ac-ft/yr (0.8 percent). Further investigation of design assumptions and regulatory constraints associated with closing or modifying the outlets of existing SCS/FRS projects is necessary to assess feasibility.

5. Water Potentially Available at Selected Locations

The Guadalupe - San Antonio River Basin Model was used to estimate monthly quantities of water potentially available at the following locations:

- San Marcos River Below the Blanco River Confluence;
- Guadalupe River Below the Comal River Confluence; and
- Canyon Lake.

Calculations were performed subject to two general scenarios selected to present the reasonable range of water potentially available during average and drought conditions without consideration of instream flow and/or estuarine inflow requirements:

Scenario 1: Full utilization of existing water rights based on springflows resulting from a fixed Edwards Aquifer pumpage rate of 450,000 ac-ft/yr. Water potentially available under this scenario is comparable to unappropriated flow.

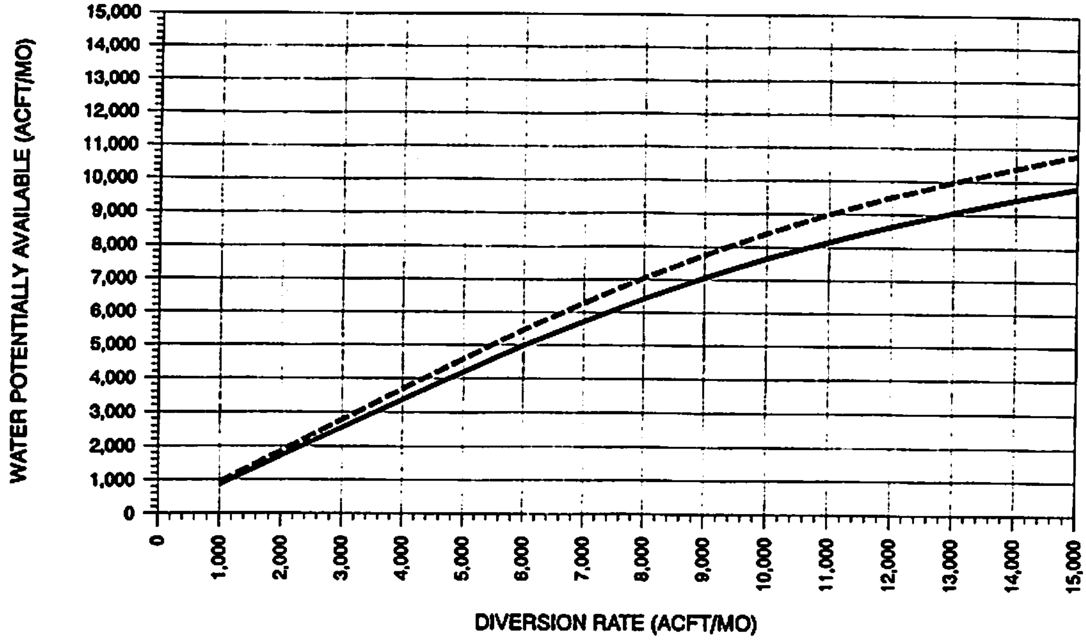
Scenario 2: Utilization of existing water rights to the extent reported in 1988 based on springflows resulting from a fixed Edwards Aquifer pumpage rate of 250,000 ac-ft/yr. Diversion of water potentially available under this scenario implicitly assumes that it would be necessary to purchase existing water rights which were not used in 1988.

Average quantities of water potentially available which are reported herein are theoretical maximums and may be subject to significant reductions due to economic, environmental, structural, and political limitations.

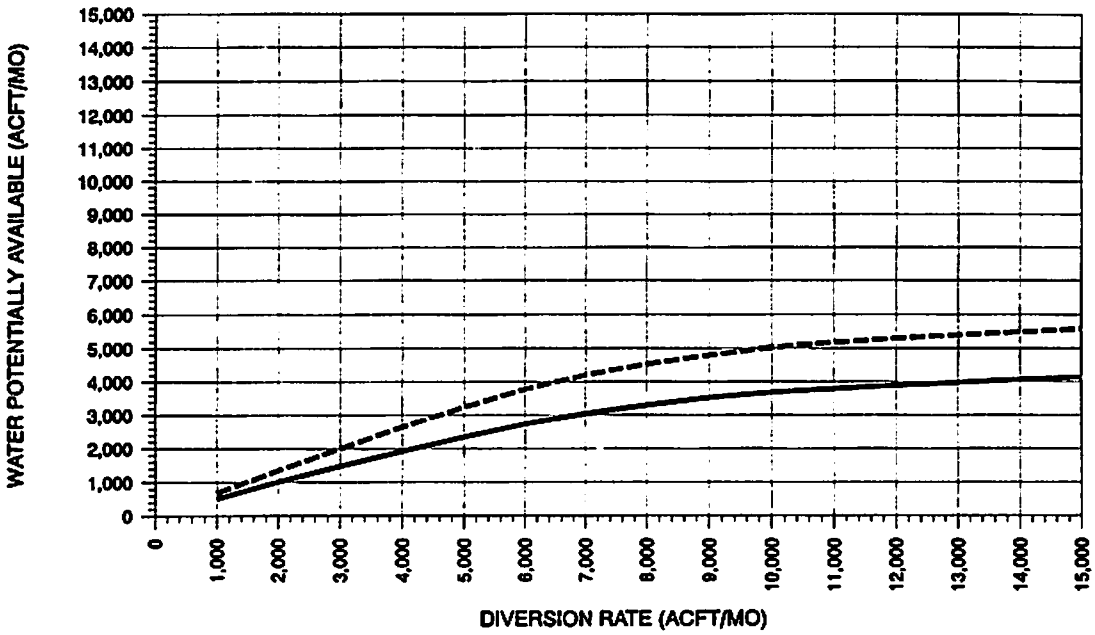
Figure ES5-1 presents estimates of water potentially available at the selected location on the San Marcos River based on diversion rates ranging from 1,000 ac-ft/month (17 cfs) to 15,000 ac-ft/month (250 cfs). Operating under Scenario 1 with a 6,000 ac-ft/month (100 cfs) diversion rate, for example, a long-term average of approximately 5,000 ac-ft/month (60,000 ac-ft/yr) and a drought average of approximately 2,750 ac-ft/month (33,000 ac-ft/yr) might be available. While increased quantities of water potentially available could be obtained under Scenario 2 or by increasing diversion rate, Figure ES5-1 reveals that availability does not increase uniformly with diversion rate and does, in fact, begin to approach a maximum. Furthermore, it is important to note that there would be no water available at this location under either scenario approximately 13 percent and 45 percent of the time subject to average and drought conditions, respectively.

Figure ES5-2 presents estimates of water potentially available on the Guadalupe River below the Comal River confluence based on diversion rates ranging from 1,000 ac-ft/month (17 cfs) to 15,000 ac-ft/month (250 cfs). Operating under Scenario 1 with a 6,000 ac-ft/month (100 cfs) diversion rate, a long-term average of only about 1,250 ac-ft/month (15,000 ac-ft/yr) and a drought average of only about 250 ac-ft/month (3,000 ac-ft/yr) might be available. Under this scenario, no water would be available at the selected location between 78 percent and 95 percent of the time subject to average and drought conditions, respectively. For the same diversion rate under Scenario 2, however, about 5,500 ac-ft/month (66,000 ac-ft/yr) and 3,900 ac-ft/month (46,800 ac-ft/yr) might be available subject to average and drought conditions, respectively. Under Scenario 2, no water would be available at the selected location between 12 percent and 44 percent of the time subject to average and drought conditions, respectively. Estimates of water potentially available in the Guadalupe River are significantly more sensitive to assumptions regarding Edwards Aquifer

SAN MARCOS RIVER BELOW THE BLANCO RIVER CONFLUENCE
AVERAGE CONDITIONS (1934-89)



SAN MARCOS RIVER BELOW THE BLANCO RIVER CONFLUENCE
DROUGHT CONDITIONS (1947-56)



—— SCENARIO 1: FULL WATER RIGHTS, PUMPAGE = 450,000 ACFT/YR
– – – SCENARIO 2: 1988 WATER USAGE, PUMPAGE = 250,000 ACFT/YR

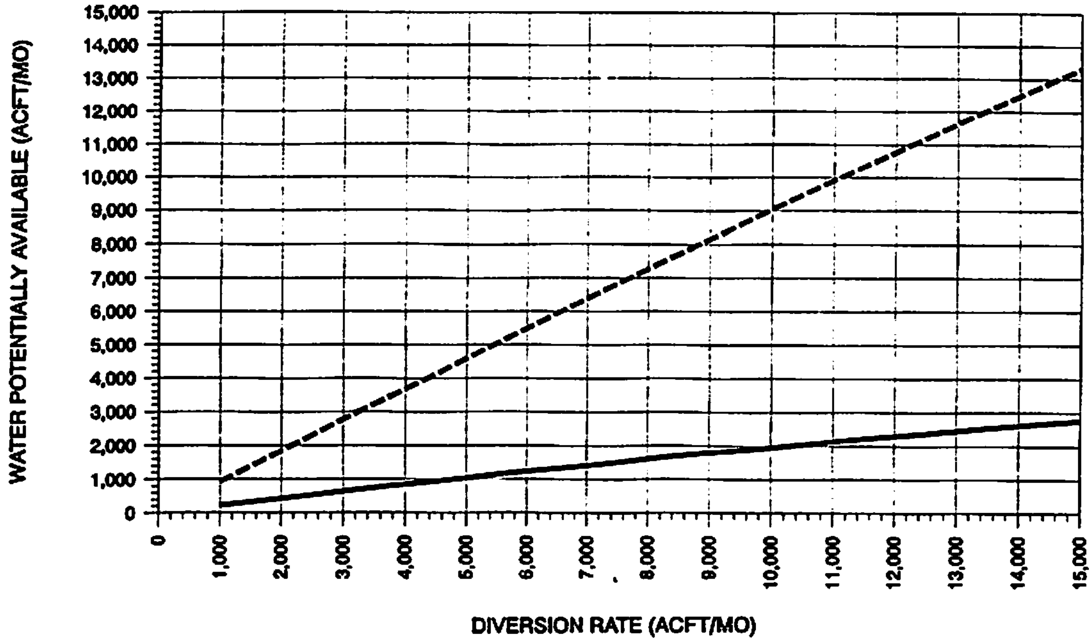
GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

WATER POTENTIALLY AVAILABLE SAN MARCOS RIVER

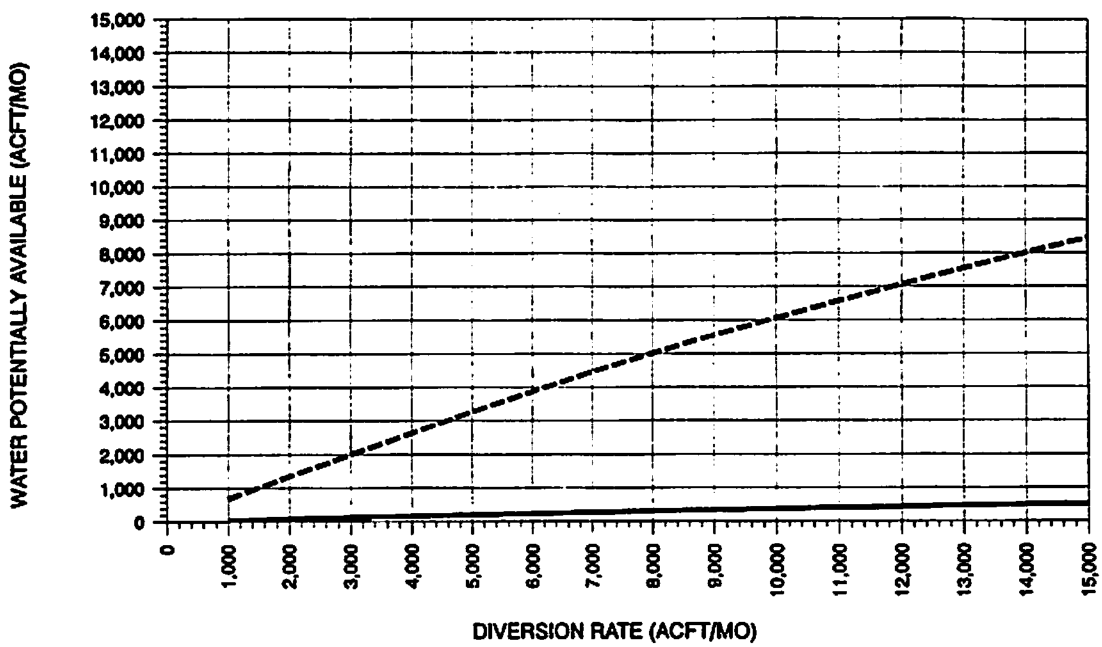
HDR Engineering, Inc.

FIGURE ES5-1

GUADALUPE RIVER BELOW THE COMAL RIVER CONFLUENCE
AVERAGE CONDITIONS (1934-89)



GUADALUPE RIVER BELOW THE COMAL RIVER CONFLUENCE
DROUGHT CONDITIONS (1947-56)



—— SCENARIO 1: FULL WATER RIGHTS, PUMPAGE = 450,000 ACFT/YR
– – – SCENARIO 2: 1988 WATER USAGE, PUMPAGE = 250,000 ACFT/YR

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

WATER POTENTIALLY AVAILABLE
GUADALUPE RIVER

HDR Engineering, Inc.

FIGURE ES5-2

pumpage/springflow and water rights utilization than are those for the San Marcos River.

Development of estimates of water potentially available (unutilized firm yield) from Canyon Lake was substantially more complex than the estimation of water potentially available at selected stream locations. The added complexity is attributable to the complicated relationship between the firm yield of Canyon Lake and Edwards Aquifer pumpage and resulting springflows, subordination of hydroelectric rights, and losses in delivery of inflows passed through or storage released from Canyon Lake in fulfillment of downstream obligations. For the purposes of this study, utilization of Canyon yield is comprised of releases and direct diversions from the lake and is defined to be the difference between the volume necessary to meet senior water rights and volume necessary to meet both senior water rights and contractual obligations. The GSA Model does not make releases from Canyon Lake storage to meet senior downstream water rights. Water potentially available or unutilized firm yield is, for purposes of this study, defined to be, the annual difference between firm yield and utilization.

Previous studies sponsored by the Guadalupe - Blanco River Authority (GBRA) indicate that the firm yield based on historical springflows, full water rights, and subordination of GBRA hydroelectric rights to 600 cfs is about 50,000 ac-ft/yr which is consistent with the permitted annual diversion from Canyon Lake. Operating under Scenario 1 and meeting all current contractual obligations (with the exception of make-up water for Coleto Creek Reservoir which was delivered as needed), utilization of Canyon firm yield was estimated to average approximately 30,500 ac-ft/yr with a maximum utilization of about 47,900 ac-ft in 1956 and a typical utilization of about 28,200 ac-ft/yr when no releases for Coleto Creek Reservoir were necessary. Hence, an average of approximately 19,500 ac-ft/yr is potentially available at Canyon Lake under the existing diversion right of 50,000 ac-ft/yr. Comparing contractual obligations which total about 25,000 ac-ft/yr (excluding Central Power & Light at Coleto Creek Reservoir) with the typical utilization of 28,200 ac-ft/yr indicates that, on the average, about 3,200 ac-ft/yr or 11 percent is lost in delivery. In the event of further subordination of GBRA hydroelectric rights, the firm yield of Canyon Lake would increase and additional quantities of water from Canyon Lake could become available.

6. Conclusions

Significant study findings and conclusions are as follows:

1) The potential for recharge enhancement estimated in this report is a theoretical maximum and, on more detailed review, will likely be subject to significant reductions due to economic, environmental, structural, and political limitations. When analyzed as a part of a total regional water resources program, there may be other types of water resource projects which provide greater benefits than some of the projects identified in this report.

2) Recharge of the Edwards Aquifer in the Guadalupe - San Antonio River Basin may be increased by an average of about 123,000 ac-ft/yr if all structural and operational projects identified in this report are implemented and all water rights are honored. This represents an increase of about 38.5 percent in the historical average recharge. Recharge during the 10-year drought period from 1947 through 1956 could be increased by about 66,300 ac-ft/yr or 43.3 percent of the historical average during this period.

3) If the structural and operational programs identified are fully implemented, inflows to the Guadalupe Estuary will be reduced by an average of about 53,200 ac-ft/yr. The construction of only the structural program will reduce inflows by about 31,000 ac-ft/yr. These figures represent between 3.4 and 2.0 percent of the average annual flow of the Guadalupe and San Antonio Rivers into the Guadalupe Estuary.

4) Estimates of recharge enhancement associated with the structural and operational programs are not very sensitive to the various aquifer pumpage/springflow scenarios or to the degree of water rights utilization. Recharge enhancement is typically limited by the volume of runoff reaching each site and the physical capability to impound and recharge that runoff.

5) Potentially significant quantities of water may be available in the San Marcos River below the Blanco River confluence, in the Guadalupe River below the Comal River confluence, and in Canyon Lake for recharge enhancement or other uses. Theoretical maximum quantities of water available have been presented in this report for a range of assumptions as to Edwards Aquifer pumpage/springflow and utilization of existing water rights.

6) Methods used in this study to calculate historical recharge to the Edwards Aquifer result in estimates that differ from previous estimates by the USGS. In particular, there are significant differences at Medina Lake and Diversion Lake (HDR estimates are lower), the area between the Medina River and Cibolo Creek (HDR estimates are higher), and the upper San Marcos River watershed (HDR estimates are higher). In addition, the methods used in this study show that significant recharge does occur in the Guadalupe River Basin where previous estimates by the USGS do not consider recharge in this basin.

7. Recommendations

The findings of this study indicate that recharge to the Edwards Aquifer may be substantially enhanced by the construction of additional recharge structures and/or changes in existing operational and institutional constraints. In order to determine whether these projects and/or operational changes are truly feasible and to quantify potential benefits to well yields and springflows, the following additional work is recommended:

1) Information developed in this study should be analyzed as a part of a total regional water resources program which compares the relative merits of recharge enhancement to other water supply options. After the role of recharge is determined in the regional water resources planning effort, selected recharge projects should be carried forward for additional detailed study.

2) The Texas Water Development Board model of the Edwards Aquifer should be recalibrated using the recharge values developed in this study and used to evaluate the various recharge options under consideration for the Nueces and Guadalupe - San Antonio River Basins to determine benefits to well yields and springflows.

3) Significant numbers of additional streamgages and raingages should be added to the hydrologic data collection network to more accurately calculate recharge in ungaged areas and to significantly improve the accuracy of recharge estimates in areas directly over the recharge zone. A state-of-the-art recharge calculation methodology for the Edwards Aquifer should be developed which utilizes the additional streamgages and raingages and incorporates appropriate elements of the USGS and HDR procedures. It is expected that consideration of these state-of-the-art recharge estimates will result in significant improvement in aquifer model calibration.

4) The TWDB Edwards Aquifer model and the surface water/recharge models of the Nueces and Guadalupe - San Antonio River Basins should be combined into one model to fully evaluate recharge enhancement options and to aid in the evaluation of various aquifer and surface water management alternatives.

5) Benefit/cost analyses of recharge projects (and/or operational changes) should be performed in detailed studies considering economic, environmental, geological, institutional, and structural feasibility of individual projects as well as combinations of projects.

6) Special hydrologic studies addressing the following specific items should be undertaken in support of improved recharge estimates:

- Field studies of Medina Lake and Diversion Lake to better understand and define relationships between reservoir levels and recharge and leakage rates;
- Field studies of water exchange rates between the Edwards Aquifer and the Guadalupe River downstream of Canyon Lake over a range of aquifer water levels;
- Refinement of firm yield estimates for Canyon Lake to include consideration of water delivery losses in conjunction with Edwards Aquifer pumpage/springflow scenarios and potential subordination of hydroelectric rights;
- Consideration of new geologic mapping of Bexar, Comal, and Hays Counties nearing completion by the USGS which should result in improved recharge zone definition and more accurate recharge basin drainage areas; and
- Investigation of the possibility of calculating historical total daily flow estimates (including flows which are not springflows) for the USGS San Marcos River springflow gage to provide more accurate historical recharge estimates for the upper San Marcos River watershed. This is similar to the procedure used at the USGS Comal River gage.