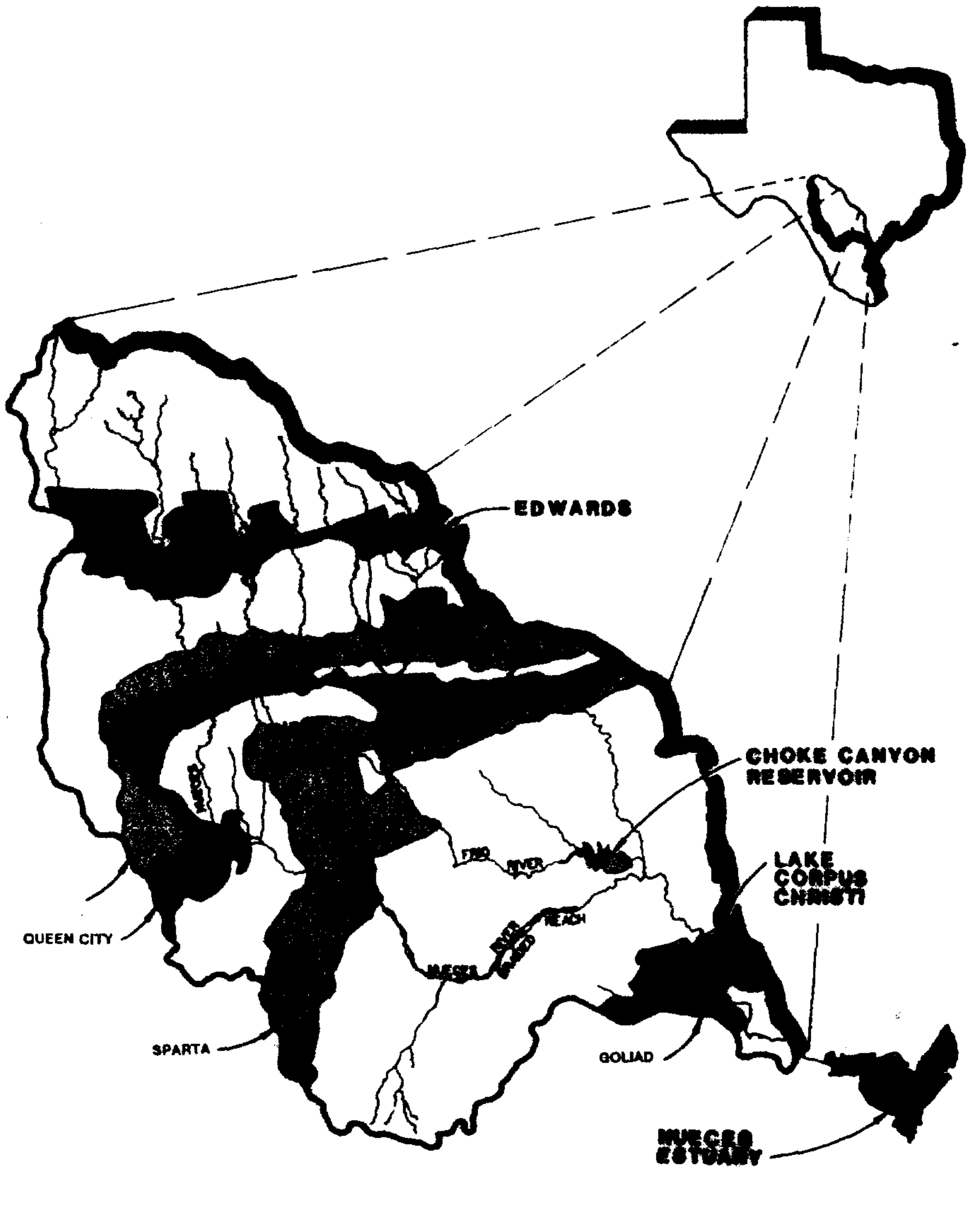
Regional Water Supply Planning Study - Phase I

Nueces River Basin

Volume I - Executive Summary



Nueces River Authority

City of Corpus Christi

Edwards Underground Water District

South Texas Water Authority

Texas Water Development Board

HDR Engineering, Inc.

REGIONAL WATER SUPPLY PLANNING STUDY

NUECES RIVER BASIN

VOLUME I - EXECUTIVE SUMMARY

Prepared for

Nueces River Authority
City of Corpus Christi
Edwards Underground Water District
South Texas Water Authority
Texas Water Development Board

by

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and
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May, 1991

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for
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Nueces River Basin

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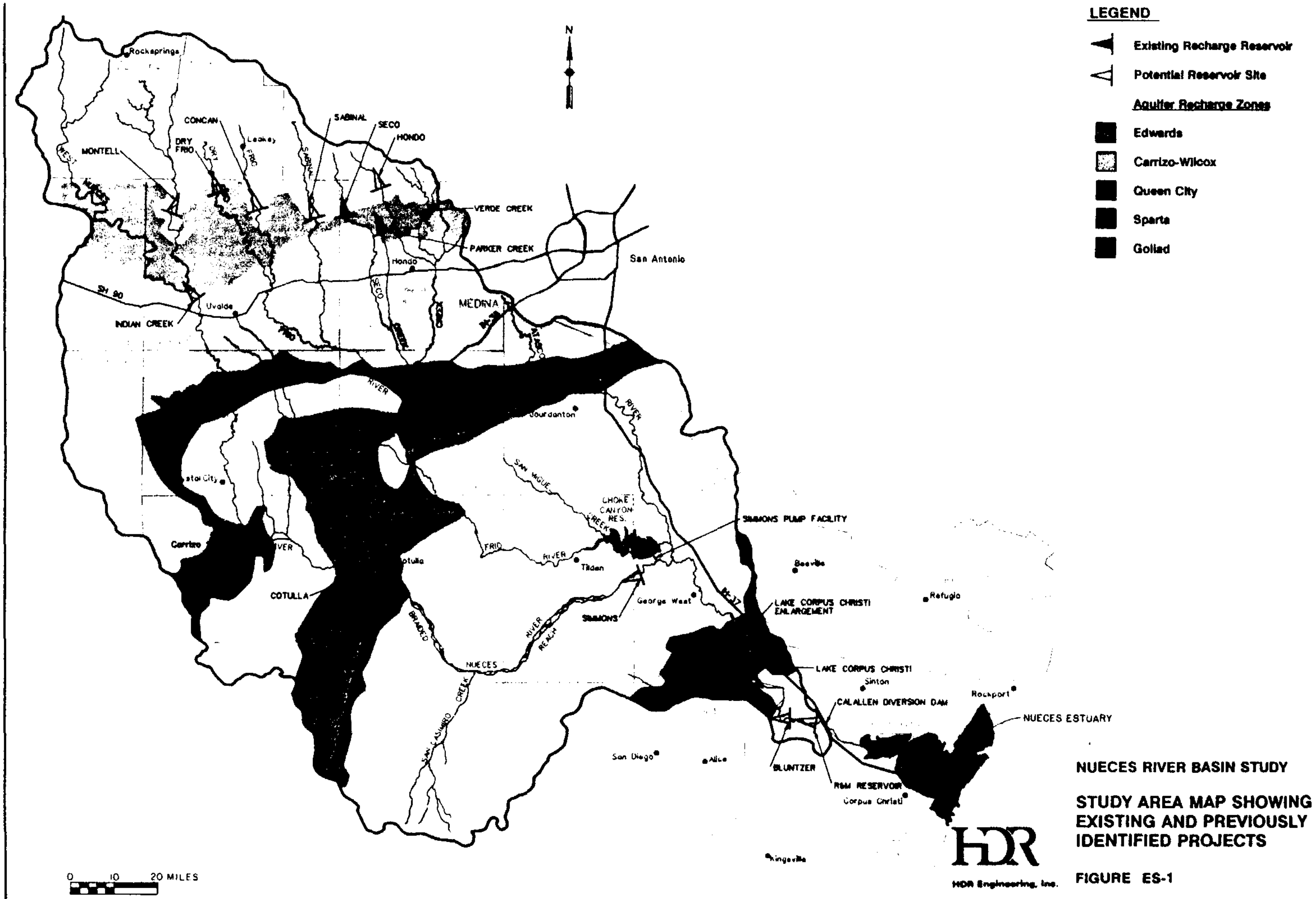
1. Study Background and Objectives

The study area consists primarily of the Nueces River Basin, which covers an area of approximately 17,000 square miles in South Texas as shown in Figure ES-1. Several entities interested in the potential development of additional water supplies in the basin, along with the Texas Water Development Board (TWDB), have jointly participated in the performance of this study. These four entities are:

Nueces River Authority (Authority);
City of Corpus Christi;
Edwards Underground Water District (EUWD); and
South Texas Water Authority (STWA).

Over the past several decades, increasing water demands on the Edwards Aquifer have raised concerns about the ability of the aquifer to meet these demands without causing social, economic, and environmental problems. The headwaters of the Nueces River Basin contribute about 57 percent of the total volume of surface water recharge to the San Antonio portion of the Edwards Aquifer. Streams crossing the Edwards Aquifer recharge zone lose a significant portion of their flow through faults and solution cavities in the limestone formations. A large portion of the runoff from the headwater area, however, occurs during storms which exceed the capacity of the recharge zone. It has been suggested that, if recharge enhancement structures were constructed, aquifer water levels, well yields, and springflows would benefit.



NUECES RIVER BASIN STUDY

STUDY AREA MAP SHOWING EXISTING AND PREVIOUSLY IDENTIFIED PROJECTS

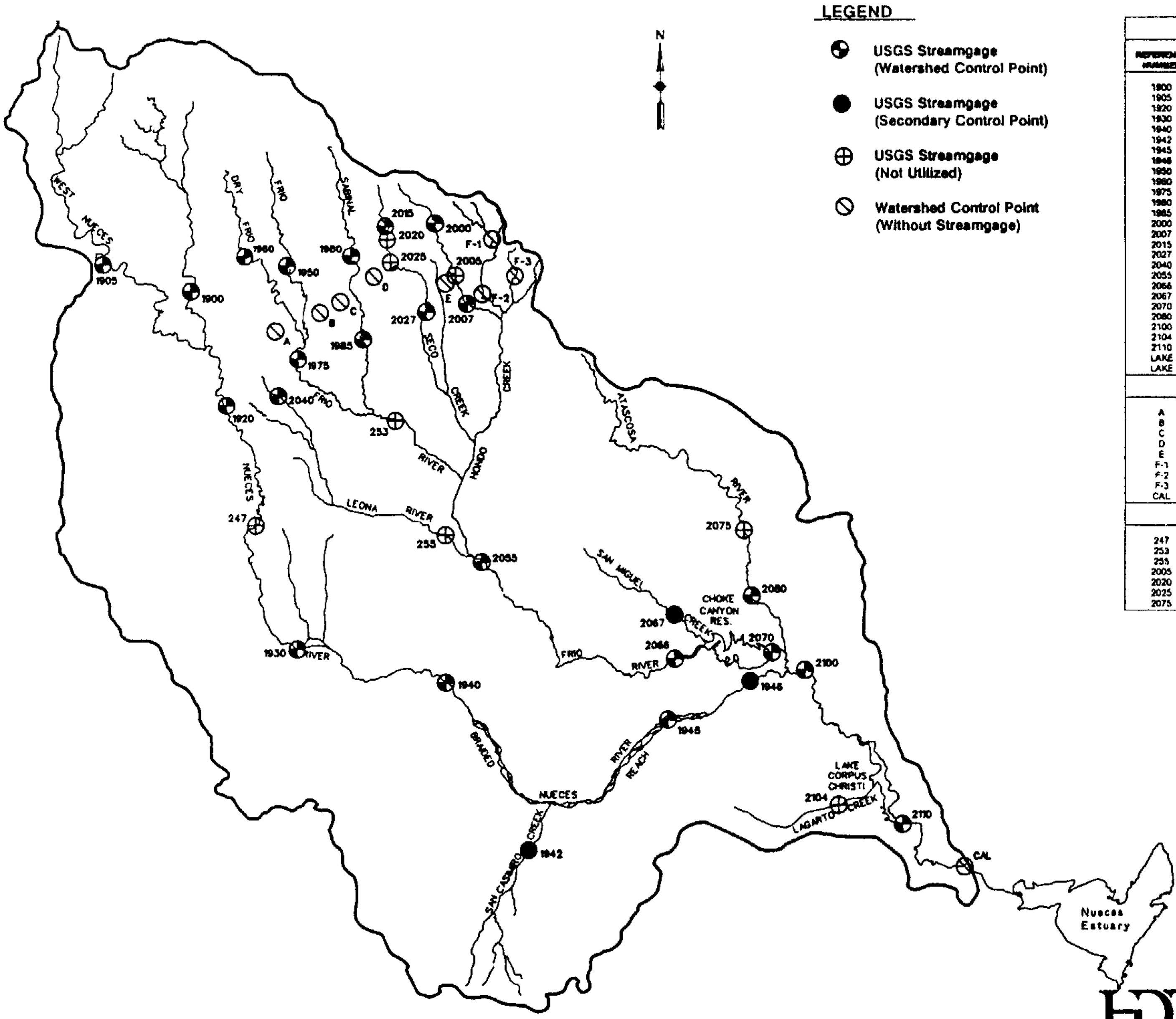
FIGURE ES-1

The concept of building recharge structures is not new. In 1964, the U.S. Army Corps of Engineers (COE) identified numerous potential sites for recharge projects. Since 1974, the Edwards Underground Water District has undertaken the construction of three small recharge projects in the basin. The locations of the EUWD recharge projects as well as the locations of those projects identified by the COE (and others) are shown in Figure ES-1.

Approximately 98 percent of the drainage area of the Nueces River basin is located upstream of the Choke Canyon Reservoir/Lake Corpus Christi System (CC/LCC System). The locations of these two reservoirs are shown in Figure ES-1. The CC/LCC System is operated by the City of Corpus Christi, with the majority of water being diverted from the system at the Calallen Diversion Dam located 35 miles downstream of Lake Corpus Christi. At this location, the water is diverted from the river and distributed to various municipal and industrial users. The CC/LCC System is the primary source of municipal and industrial water supply for a significant portion of the Texas Coastal Bend. Reductions in the inflows to these two reservoirs that could result from the construction of additional recharge projects is an important consideration in the evaluation of any recharge program.

Ongoing studies of the Nueces Estuary, which include Nueces, Corpus Christi, Oso, and Redfish Bays and a portion of the Laguna Madre, by the Texas Water Development Board (and others) have shown that freshwater inflows play an important role in the productivity and viability of the estuary. Reduction of inflow to the Nueces Estuary that could result from the construction of additional recharge structures is also an important consideration.

The primary objectives of this study are listed below and were accomplished through the development and application of a computer model of the Nueces River Basin.



SUMMARY OF GAGED WATERSHED AREAS USED IN STUDY			
REFERENCE NUMBER	LOCATION	DRAINAGE AREA (SQ. MI.)	PERIOD OF RECORD
1900	NUECES R., LAGUNA	737	10/23-12/89
1905	W. NUECES R., BRACKETTVILLE	694	10/39-9/50, 4/56-12/89
1920	NUECES R., UVALDE	1,861	10/27-12/89
1930	NUECES R., ASHERTON	4,082	10/39-12/89
1940	NUECES R., COTULLA	5,171	11/23-12/89
1942	SAN CASIMIRO C., FREER	469	1/62-12/89
1945	NUECES R., TILDEN	8,093	12/42-12/89
1948	NUECES R., SIMMONS	8,561	4/65-9/77
1950	FRIO R., CONCAN	389	11/23-9/29, 10/30-12/89
1960	DRY FRIO R., REAGAN WELLS	126	9/52-12/89
1975	FRIO R., UVALDE	631	9/52-12/89
1980	SABINAL R., SABINAL	206	10/42-12/89
1985	SABINAL R., SABINAL	241	9/52-12/89
2000	HONDO C., TARPLEY	95.6	9/52-12/89
2007	HONDO C., HONDO	149	10/60-12/89
2015	SECO C., UTOPIA	45.0	5/61-12/89
2027	SECO C., D'HANIS	168	10/60-12/89
2040	LEONA R., UVALDE	SPRING	1/39-9/65
2055	FRIO R., DERBY	3,429	8/15-12/89
2066	FRIO R., TILDEN	4,493	10/78-12/89
2067	SAN MIGUEL C., TILDEN	783	2/64-12/89
2070	FRIO R., CALLIHAM	5,491	10/24-4/26, 5/32-6/81
2080	ATASCOSA R., WHITSETT	1,171	10/25-4/26, 6/32-12/89
2100	NUECES R., THREE RIVERS	15,427	7/15-12/89
2104	LAGARTO C., GEORGE WEST	155	10/71-12/89
2110	NUECES R., MATHIS	16,660	9/39-12/89
LAKE	CHOKE CANYON RESERVOIR	5,490	10/82-12/89
LAKE	LAKE CORPUS CHRISTI	16,656	9/48-12/89
SUMMARY OF UNGAGED AREAS USED IN STUDY			
A	LEONA RIVER	36	N/A
B	HACKBERRY & BLANCO CREEKS	32	N/A
C	LITTLE BLANCO & NOLTON CREEKS	18	N/A
D	RANCHERO CREEK	6	N/A
E	PARKERS & LIVE OAK CREEKS	12	N/A
F-1	VERDE C. ABOVE RECHARGE ZONE	55	N/A
F-2	VERDE C. IN RECHARGE ZONE	105	N/A
F-3	RECHARGE ZONE - OTHER	47	N/A
CAL	CALALLEN DIVERSION DAM	16,920 (E)	N/A
SUMMARY OF GAGES NOT USED IN STUDY			
247	NUECES R., CINONIA	2,150 (E)	8/15-9/25
253	FRIO R., FRIO TOWN	1,460 (E)	5/24-9/27
255	LEONA R., DIVOT	565 (E)	5/24-9/29
2005	HONCO C., HONDO	132	8/52-10/64
2020	SECO C., UTOPIA	53.2	8/52-9/61
2025	SECO C., D'HANIS	87.4	8/52-10/64
2075	ATASCOSA R., McCOY	530	8/51-8/57

NUECES RIVER BASIN STUDY

WATERSHED CONTROL POINT AND STREAMGAGE LOCATION MAP

HDR Engineering, Inc.

FIGURE ES-3

* Determine the potential for increasing artificial recharge to the Edwards Aquifer through construction of additional recharge structures in the Nueces River Basin;

* Calculate the firm yield of the Choke Canyon Reservoir/Lake Corpus Christi System with and without additional recharge structures; and

* Quantify the potential impacts of additional recharge structures on inflows to the Nueces Estuary.

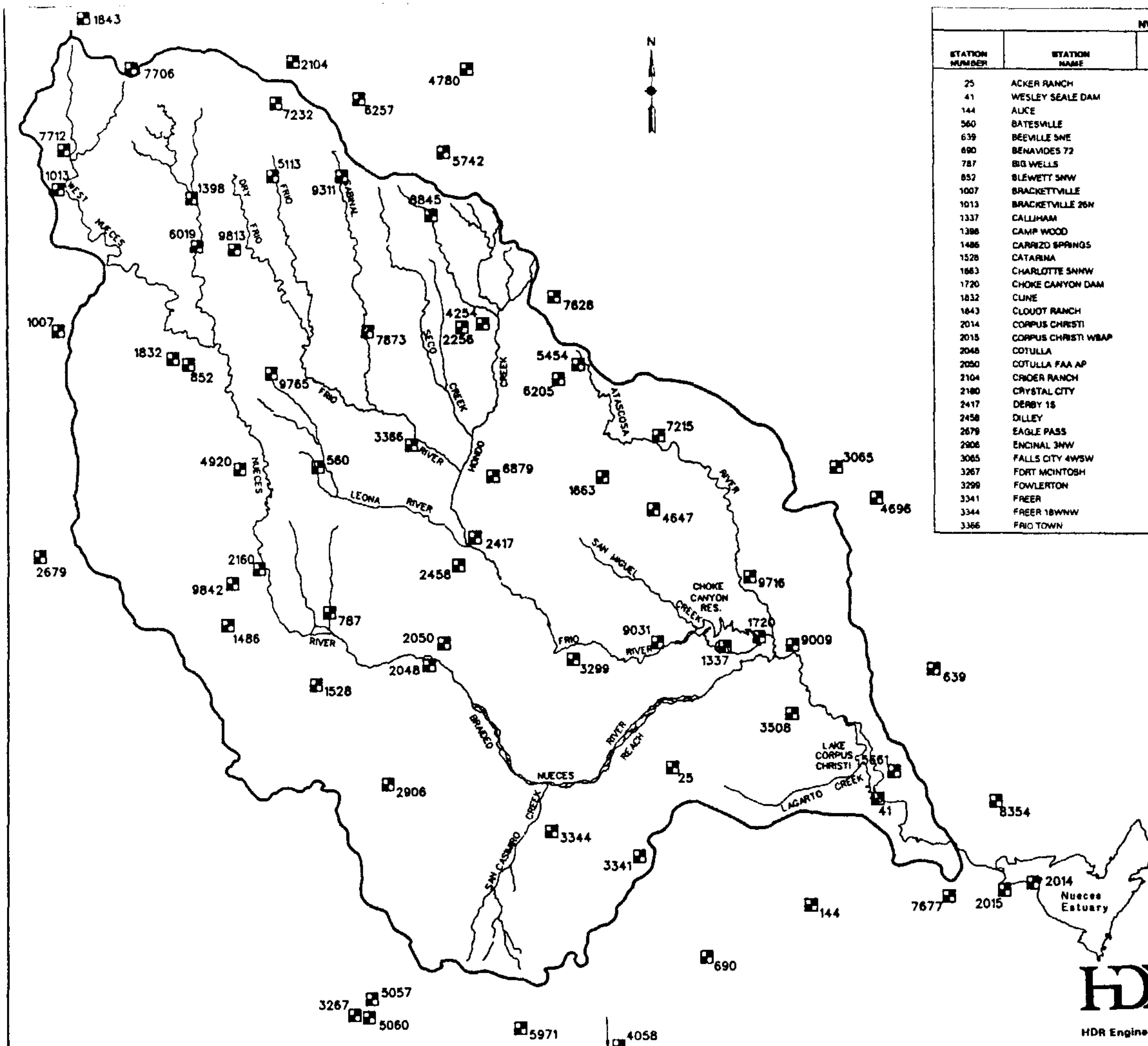
Additional objectives of the study included:

* Independent evaluation of U.S. Geological Survey (USGS) estimates of historical natural recharge to the Edwards Aquifer from the Nueces River Basin;

* Estimation of future water demands for the Nueces River Basin through the year 2040 with emphasis on estimating future demands of the CC/LCC service area;

* Evaluation of the firm yield of the CC/LCC System with respect to its ability to meet future demands through the year 2040; and

* Development of recommendations for additional study.



NWS AND TWDB PRECIPITATION STATIONS

STATION NUMBER	STATION NAME	PERIOD OF RECORD USED IN STUDY	STATION NUMBER	STATION NAME	PERIOD OF RECORD USED IN STUDY
25	ACKER RANCH	1979-89	3508	GEORGE WEST	1916-89
41	WESLEY SEALE DAM	1966-89	4058	HEBRONVILLE	1916-45, 1952-89
144	ALICE	1916-48, 1952-89	4254/4256	HONDO & HONDO WSMO AP	1916-89
560	BATESVILLE	1966-89	4647	JOURDANTON	1949-89
639	BEEVILLE 5NE	1916-89	4696	KARNES CITY	1932-89
690	BENAVIDES 72	1966-89	4780	KERRVILLE	1916-48
787	BIG WELLS	1916-89	4920	LA PRYOR	1916-78
852	BLEWETT 5NW	1966-78	5057/5060	LAREDO WB AP & #2	1949-89
1007	BRACKETTVILLE	1916-89	5113	LEAKEY	1952-89
1013	BRACKETVILLE 26N	1979-89	5454	LYTLE	1979-89
1337	CALLIHAM	1979-89	5661	MATHIS	1966-89
1398	CAMP WOOD	1944-89	5742	MEDINA	1966-89
1486	CARRIZO SPRINGS	1932-89	5971	MIRANDO CITY	1949-65
1528	CATARINA	1966-78	6019	MONTELL	1916-43
1663	CHARLOTTE 5NNW	1966-89	6205	NATALIA	1944-48, 1952-78
1720	CHOKE CANYON DAM	1982-89	6257	NELSON RANCH	1966-78
1832	CLINE	1944-51	6879	PEARSALL	1916-89
1843	CLOUDT RANCH	1949-51	7215	POTEET	1944-89
2014	CORPUS CHRISTI	1949-78	7232	PRADE RANCH	1966-78
2015	CORPUS CHRISTI WBAP	1949-89	7628	RIO MEDINA 2N	1932-89
2048	COTULLA	1916-89	7677	ROBSTOWN	1952-89
2050	COTULLA FAA AP	1952-78	7706	ROCKSPRINGS	1932-89
2104	CRIDER RANCH	1949-65	7712	ROCKSPRINGS 18SW	1966-89
2160	CRYSTAL CITY	1949-89	7873	SABINAL 1WSW	1916-89
2417	DERBY 1S	1979-89	8354	SINTON	1932-78
2458	DILLEY	1916-78	8845	TARPLEY	1938-65
2679	EAGLE PASS	1916-89	9009	THREE RIVERS	1932-89
2906	ENCINAL 3NW	1916-89	9031	TILDEN	1952-89
3065	FALLS CITY 4WSW	1949-89	9265	UVALDE	1916-89
3267	FORT MCINTOSH	1916-31	9311	VANDERPOOL	1979-89
3299	FOWLERTON	1916-89	9716	WHITSETT 3SW	1916-51
3341	FREER	1949-89	9813	WILSON RANCH	1949-51
3344	FREER 18WNW	1979-89	9842	WINTERHAVEN EXP STA	1949-65
3366	FRIO TOWN	1949-78			

LEGEND

PRECIPITATION STATION

NUECES RIVER BASIN STUDY

PRECIPITATION STATION LOCATION MAP

HDR Engineering, Inc.

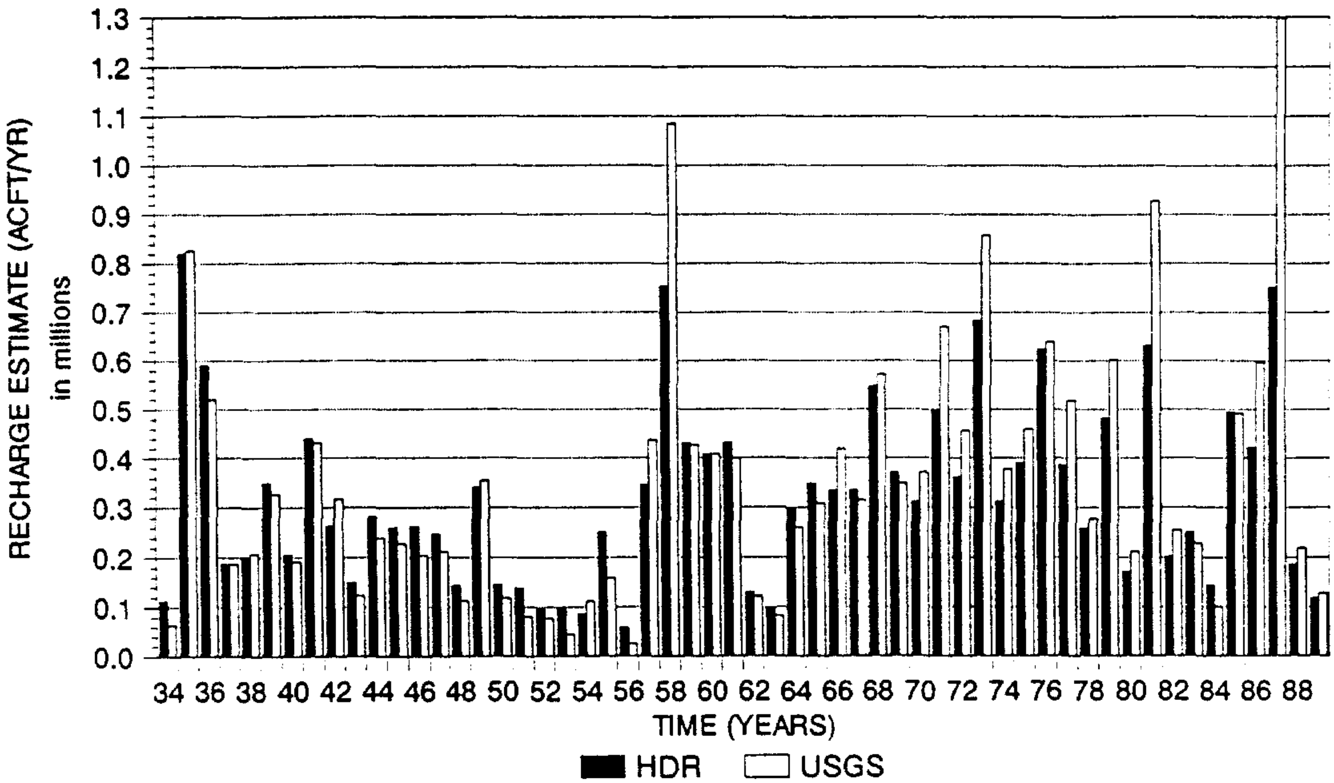
FIGURE ES-4

2. Development of Nueces River Basin Model

Numerous published and unpublished sources of information were used in developing the input database for the Nueces River Basin model. A review of available streamflow, precipitation, and water use records indicated that the 56-year period from 1934 through 1989 could be adequately analyzed and was selected for the model. This historical period contains several severe drought cycles including the droughts of the 1950's, 1960's, and 1980's. The 1934 through 1989 period also corresponds to the base period for which the USGS has developed estimates of historical recharge to the Edwards Aquifer. A summary of the data used in the model along with the corresponding source(s) is presented in Table ES-1.

Figure ES-3 shows the locations of the USGS streamgages and ungaged control points used to develop monthly streamflows and channel loss rates for the model. Twenty-nine of these locations were included as primary control points in the model. Figure ES-4 shows the locations of all raingages used at various times throughout the study period in developing estimates of storm runoff and net evaporation. All of these raingages are operated by either the National Weather Service (NWS) or the Texas Water Development Board.

The Nueces River Basin model operates on a monthly time step proceeding with flow calculations in an upstream to downstream order considering recharge, channel losses, water rights, and selected reservoirs. For the selected reservoirs, monthly inflows, evaporation, reservoir leakage to recharge, releases, and water supply demands were considered in computing spills and monthly contents. For recharge reservoirs which are expected to hold water for less than a month after filling, evaporation was not calculated. The model is capable of reproducing historical flows at all control point locations.



NUECES RIVER BASIN STUDY

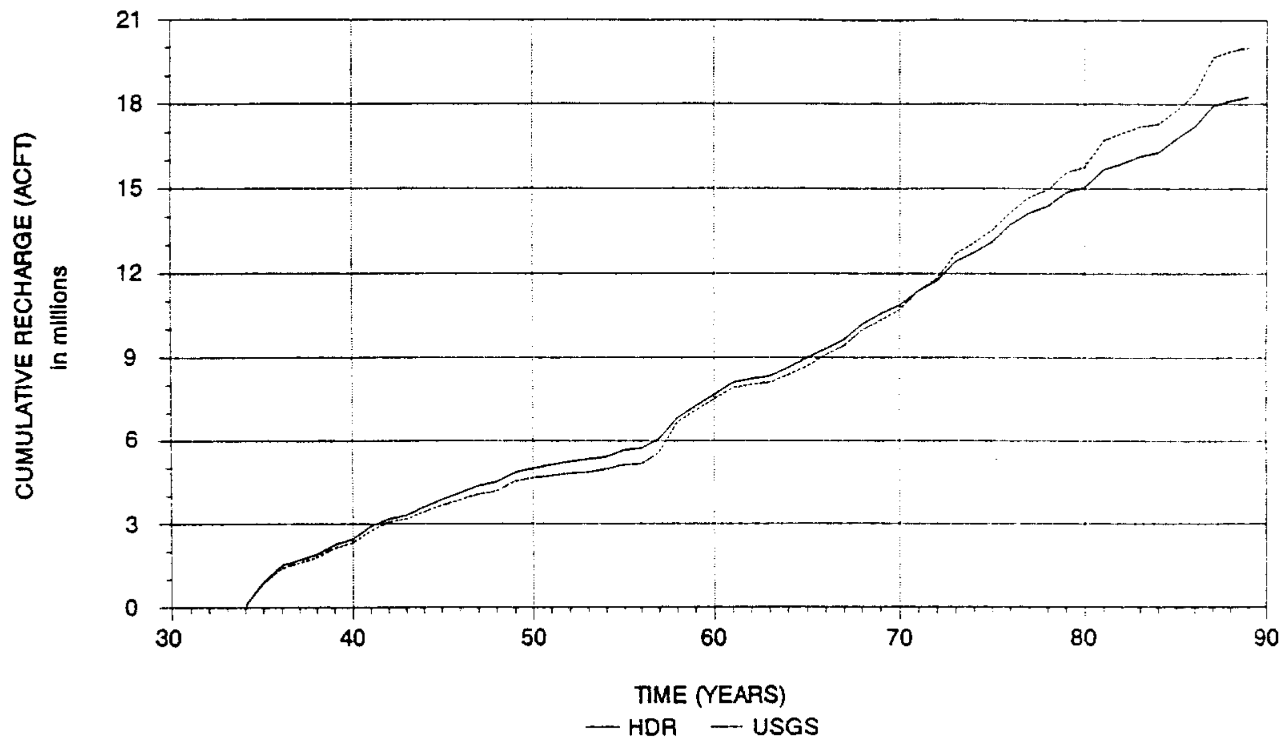
COMPARISON OF HISTORICAL EDWARDS AQUIFER RECHARGE FOR NUECES RIVER BASIN

HDR Engineering, Inc.

FIGURE ES-5

Table ES-1
Summary of Data Sources Used in Development of Nueces River Basin Model

Data	Source
Streamflow	U.S. Geological Survey
Historical Water Right Diversions	Texas Water Commission
Water Right Permits	Texas Water Commission
Precipitation	National Weather Service Texas Water Development Board Local Observers
Well Levels	Edwards Underground Water District
Evaporation	Texas Water Development Board City of Corpus Christi Texas A & M University System
Reservoir Capacity	Lake Corpus Christi - 1987 USGS Study (modified by HDR). Choke Canyon Reservoir - City of Corpus Christi. Montell, Concan, Upper Sabinal - 1964 Corps Of Engineers Study. Upper Dry Frio, Indian Creek - studies by others. Other sites planimetered from USGS maps or estimated from nearby site.
Recharge Reservoir Release Rates	USGS - 1983 study of losses across recharge zone.
Water Delivery Losses	Below Lake Corpus Christi - 1968 TWDB Study
Return Flows	CC/LCC Service Area - Texas Water Development Board



EDWARDS AQUIFER RECHARGE
NUECES RIVER BASIN

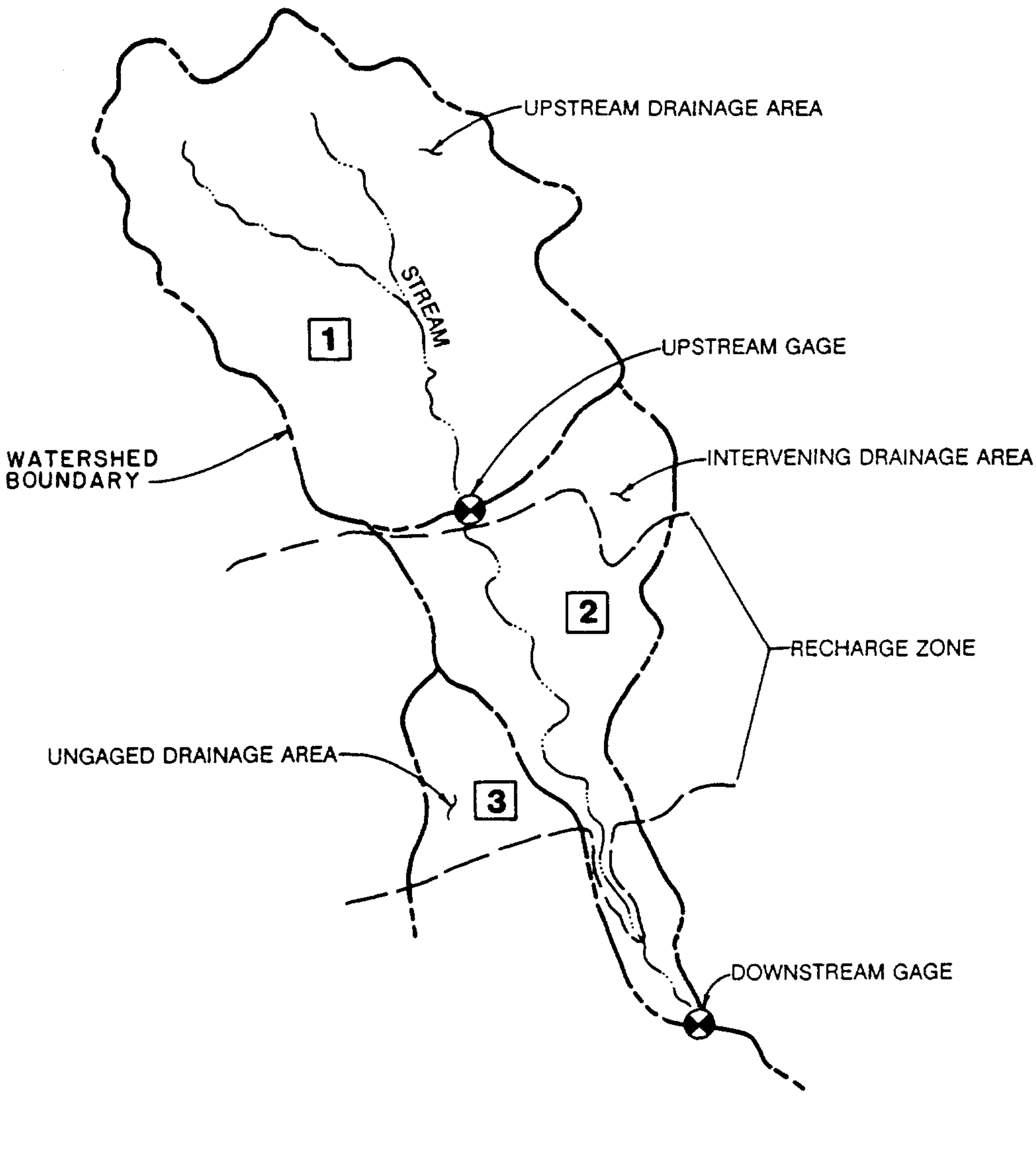
NUECES RIVER BASIN STUDY

COMPARISON OF CUMULATIVE EDWARDS AQUIFER RECHARGE FOR NUECES RIVER BASIN

HDR

HDR Engineering, Inc.

FIGURE ES-6



NUECES RIVER BASIN STUDY

SCHEMATIC OF TYPICAL GAGED AND UNGAGED AREAS NEAR RECHARGE ZONE

HDR Engineering, Inc.

FIGURE ES-7

3. Historical Recharge to the Edwards Aquifer and Comparison with USGS Recharge Estimates

Historical average annual recharge to the Edwards Aquifer for the 1934 through 1989 period for the Nueces River Basin was calculated and compared to USGS recharge estimates for the same period. This comparison shows that the previous USGS estimate of 358,000 ac-ft per year is about 10 percent higher than the estimate of 326,000 ac-ft per year computed by HDR. Although the difference in the long-term averages is only marginally significant considering the complexity of the physical process being modelled, much larger differences exist for selected periods within this 56-year period. Figure ES-5 presents a comparison of historical annual recharge estimates for the Nueces River Basin.

In order to ascertain the sources of differences between the USGS and HDR estimates, comparisons of cumulative historical recharge were considered. Cumulative historical recharge for the 1934 through 1989 period is presented in Figure ES-6. Comparisons of estimates are based on the following historical periods:

Period 1 - 1934 through 1942 (9 years);
Period 2 - 1943 through 1956 (14 years);
Period 3 - 1957 through 1970 (14 years); and
Period 4 - 1971 through 1989 (19 years).

Periods 1 and 3 show reasonably good agreement, with USGS recharge estimates averaging only 3.7 percent higher than HDR estimates. A comparison of Period 2, which contains the 1950's drought, shows that the USGS estimates averaged 18.5 percent less than recharge as computed by HDR. A comparison of Period 4, which includes the most recent period, shows the largest differences in recharge. During this period, the USGS average annual recharge was 490,000 ac-ft per year, while HDR calculated recharge of only 388,000 ac-ft per year. This is an average difference of 102,000 ac-ft per year or 26.3 percent.

The principal difference between the USGS and HDR 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 upstream gaged storm runoff (as shown in Figure ES-7) adjusted for drainage area size and precipitation differences. USGS assumes that runoff varies linearly with precipitation when adjusting for precipitation differences. The USGS method is reasonable only if the runoff potential of the soil-cover complex and the precipitation are about the same in both the upstream and intervening areas.

A review of the Soil Conservation Service (SCS) Soils Surveys for the recharge and upstream areas showed that soils in the recharge area generally have less runoff potential then soils in upstream areas. These reports show significant differences in runoff potential as a result of differences in soil grain size (clayey versus sandy soils), topography (hills versus level fields), and land use (rangeland versus cultivated fields). As a result of this review, it is believed that the drainage area ratio method used by USGS is not the most appropriate method to estimate runoff in the recharge area. HDR used a method based on SCS procedures which takes into account differences in soil-cover complexes as well as differences in rainfall.

Other differences between the USGS and HDR procedures included:

* Calculation of the delayed effects of springflows resulting from infiltration in upstream gaged areas. The HDR procedure does not account for this delay.

* The USGS computer model has apparently not been modified to account for revisions in drainage areas as published by the USGS in 1984.

* The USGS raingage weighting factors do not reflect appropriate weights based on the relative locations of the gages within the watershed.

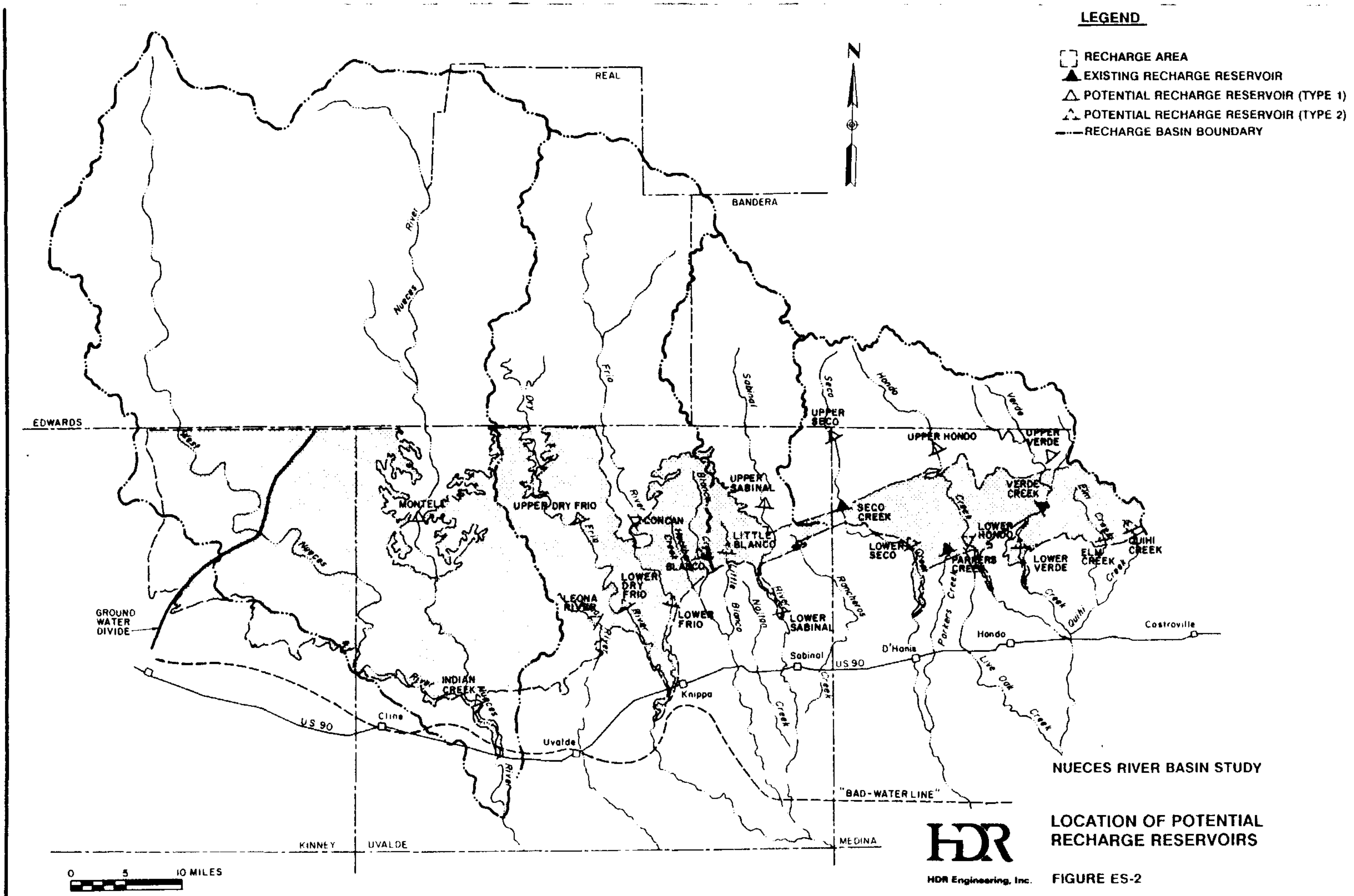
* The USGS procedure does not account for water rights diversions.

In summary, it is our opinion that the USGS method produces reasonably accurate recharge estimates in dry years, although their method may tend to slightly underestimate recharge in these years. In wet years, however, we believe that the USGS method of calculating recharge significantly overestimates recharge.

4. Additional Recharge from Potential Recharge Reservoirs

A total of 19 potential recharge reservoirs were evaluated to determine the additional volume of recharge they could provide. The location of each potential recharge site is shown in Figure ES-2. Six of these sites were previously identified in other studies, while the remaining 13 sites were located during the course of this study. These reservoirs are moderate to large size structures complete with spillways. The structures were sited and sized without consideration for economic, geologic, environmental, or human factors. The express purpose of the structures selected for analysis was the determination of the theoretical maximum additional recharge attainable. Development of these structures will likely require compromises in size, location, mitigation of wildlife habitat, and other factors that will reduce the actual additional recharge attainable from the theoretical amounts reported in this study.

Two types of recharge reservoirs were analyzed for a 56-year period of record. Type 1 reservoirs are catch and release structures and Type 2 are immediate recharge structures. Type 1 structures are located upstream of the recharge zone and are operated to release water at the maximum recharge rate of the downstream channel. Type 2 structures are located within the recharge zone. Water in the Type 2 structures recharges directly from the bottom of the reservoir and the entire volume is drained, usually within a period of less than one month. (The exception to this is the Indian Creek site located on the Nueces River, which may take more than a year to drain.) Figure ES-8 shows how both types of structures operate. The Type 2 structures are large structures which were located in the model at the downstream edge of the recharge zone to determine the maximum amount of water available for recharge. A multi-site program of smaller structures on the recharge zone may be substituted for a Type 2 structure and still accomplish the same recharge,



NUECES RIVER BASIN STUDY

HDR

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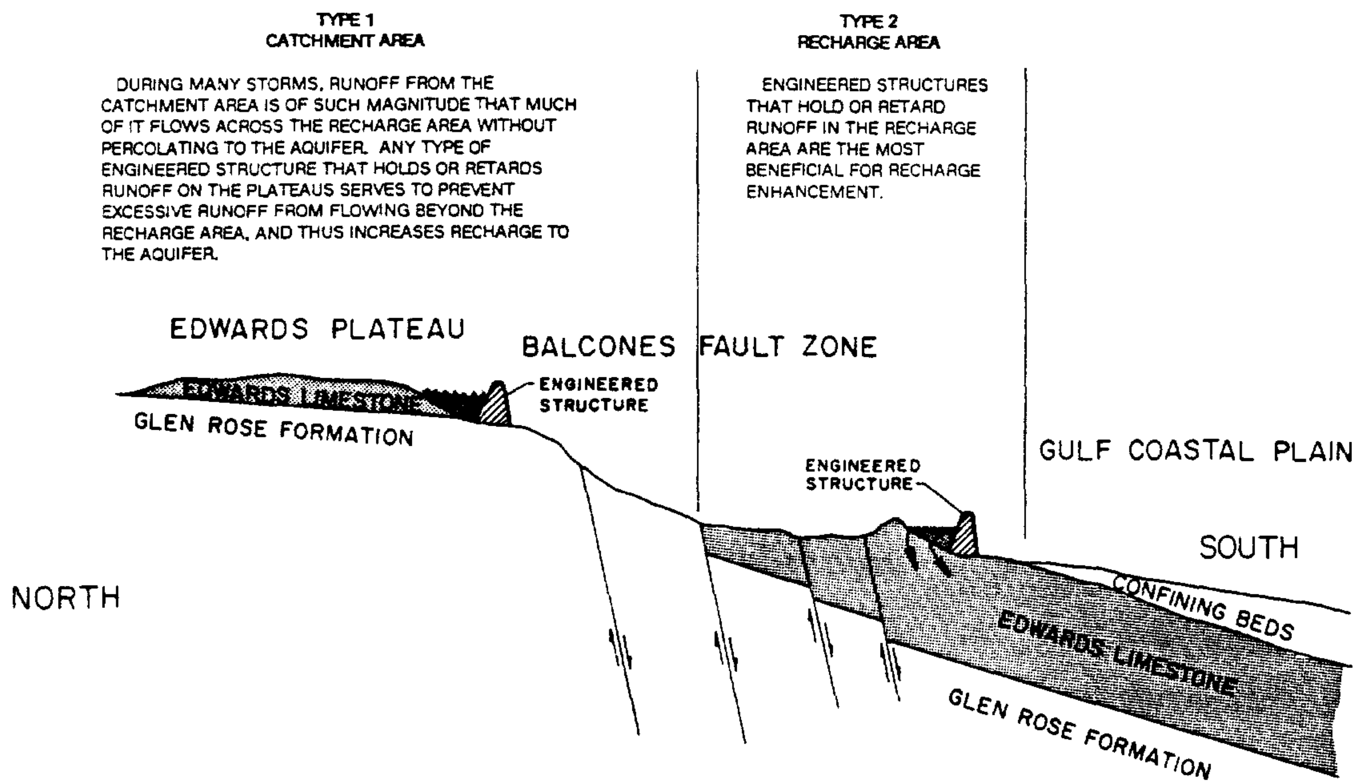
LOCATION OF POTENTIAL RECHARGE RESERVOIRS

FIGURE ES-2



SOURCE: USGS AND EUWD

NUECES RIVER BASIN STUDY

TYPES OF RECHARGE PROJECTS

HDR

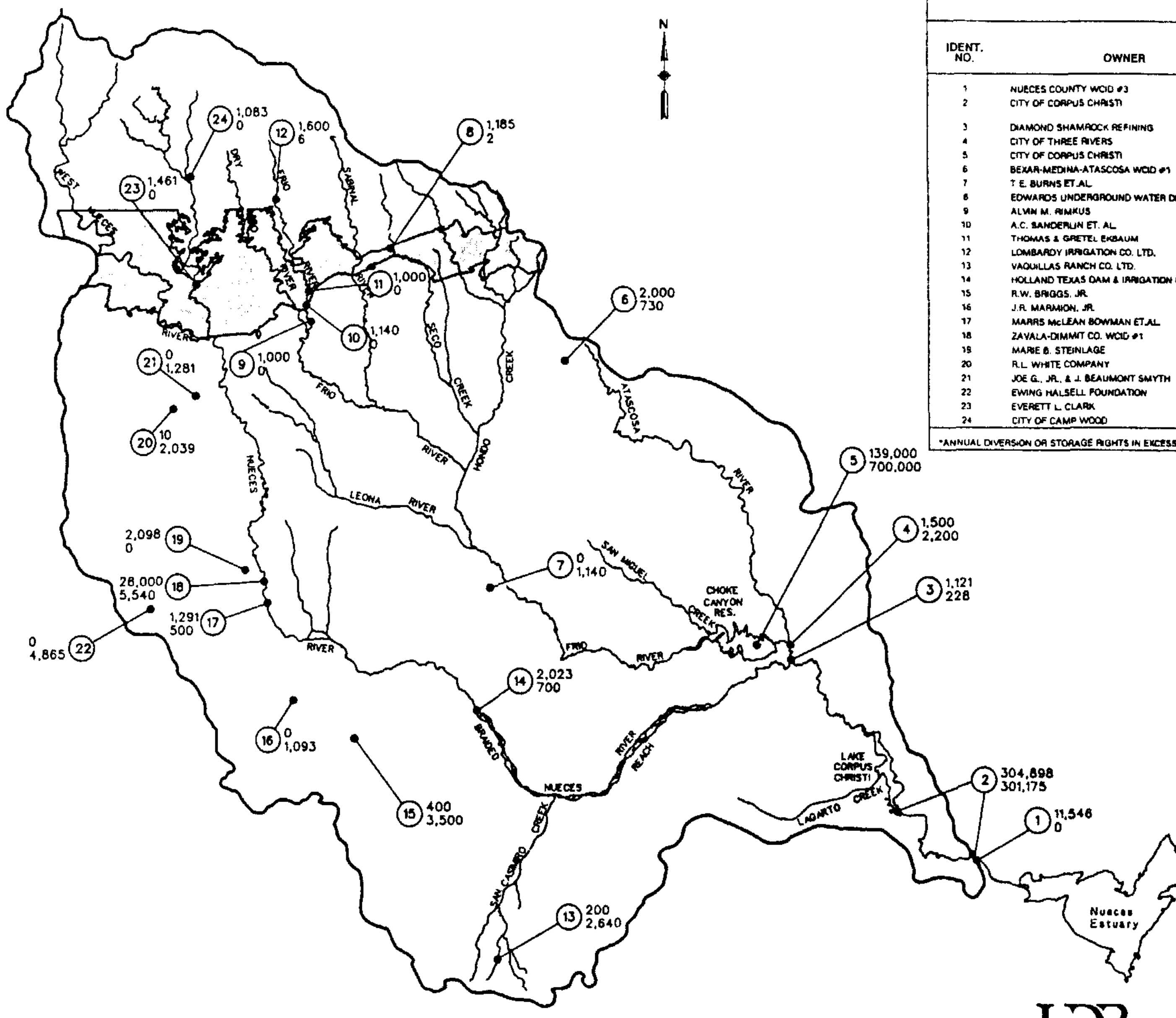
HDR Engineering, Inc. FIGURE ES-8

provided that the cumulative storage capacity and recharge rate of the multi-site program is equal to that of the Type 2 structure. In the case of the Indian Creek site with its slow recharge rate, artificial recharge by injection wells, diversion to the Dry Frio River, or a substitute multi-site program may be required to attain the computed recharge.

Reservoir operation studies were performed with the two types of recharge structures in place to determine a theoretical, but reasonable, upper limit of recharge potential. It should be noted that when the analyses were performed for the Type 1 structures, the Type 2 structures were not present in the model operation. Likewise, the Type 2 structures were analyzed without the Type 1 structures in place. Operational analyses with both Type 1 and Type 2 structures included in tandem were not performed because review of flow data indicated that the additional recharge would likely not be sufficient to justify the construction of both types of projects.

The theoretical recharge to the Edwards Aquifer was first calculated honoring all existing water rights (except for several small rights located downstream of Lake Corpus Christi). A second analysis was performed in which all water rights were honored except those of the City of Corpus Christi in the Choke Canyon/Lake Corpus Christi (CC/LCC) System and the several small rights located downstream of Lake Corpus Christi. Water rights of the City of Robstown (i.e., Nueces County WCID #3) at the Calallen Diversion Dam were among those rights honored in all analyses. The second analysis was accomplished to determine the theoretical maximum amount of recharge potential and the effects of that maximum recharge on the CC/LCC System yield.

Figure ES-9 shows the locations of significant water rights in the basin, including those of Zavala-Dimmit Counties WCID #1 and rights in the Crystal City-Carrizo Springs area. To insure protection of these (and other smaller) water rights, it will be necessary to



SIGNIFICANT WATER RIGHTS*

IDENT. NO.	OWNER	DIVERSION RIGHTS (AC-FT/YR)	STORAGE RIGHTS (AC-FT)	NOTES
1	NUECES COUNTY WCID #3	11,546	0	
2	CITY OF CORPUS CHRISTI	304,898	300,000 1,175	LAKE CORPUS CHRISTI CALALLEN RESERVOIR
3	DIAMOND SHAMROCK REFINING	1,121	228	
4	CITY OF THREE RIVERS	1,500	2,200	
5	CITY OF CORPUS CHRISTI	139,000	700,000	CHOKE CANYON RESERVOIR
6	BEXAR-MEDINA-ATASCOSA WCID #1	2,000	730	
7	T E. BURNS ET.AL.	0	1,140	
8	EDWARDS UNDERGROUND WATER DIST.	1,185	2	SECO CREEK RECHARGE DAM
9	ALVIN M. RIMKUS	1,000	0	
10	A.C. SANDERLIN ET. AL.	1,140	0	
11	THOMAS & GRETEL EKBAUM	1,000	0	
12	LOMBARDY IRRIGATION CO. LTD.	1,800	6	
13	VAQUILLAS RANCH CO. LTD.	200	2,640	
14	HOLLAND TEXAS DAM & IRRIGATION CO.	2,023	700	
15	R.W. BRIGGS, JR.	400	3,500	
16	J.R. MARMION, JR.	0	1,093	
17	MARRS McLEAN BOWMAN ET.AL.	1,291	500	
18	ZAVALA-DIMMIT CO. WCID #1	28,000	5,540	
19	MARIE B. STEINLAGE	2,098	0	
20	R.L. WHITE COMPANY	10	2,039	
21	JOE G., JR., & J. BEAUMONT SMYTH	0	1,281	
22	EWING HALSELL FOUNDATION	0	4,865	
23	EVERETT L. CLARK	1,461	0	
24	CITY OF CAMP WOOD	1,083	0	

*ANNUAL DIVERSION OR STORAGE RIGHTS IN EXCESS OF 1,000 ACRE-FEET.

LEGEND

(1) LOCATION & IDENTIFICATION NUMBER OF SIGNIFICANT WATER RIGHT

(1) 11,546 — ANNUAL DIVERSION RIGHT IN ACRE-FEET
0 — STORAGE RIGHT IN ACRE-FEET

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NUECES RIVER BASIN STUDY

SIGNIFICANT WATER RIGHTS LOCATION MAP

FIGURE ES-9

install large capacity outlet works in each of the recharge structures to allow flows to be passed at a sufficient rate to arrive downstream. Flows would only need to be passed at those times when the recharge structures would cause an additional shortage to downstream rights. This generally represents how the watermaster would require the recharge structures to be operated and is the way existing water rights were satisfied in the model.

The results of the recharge calculations with the Type 1 structures in place are presented in Table ES-2. The Type 1 structures with a combined storage of 647,600 ac-ft provide an average gain of 85,261 ac-ft per year of recharge for the 56-year period honoring all water rights. This represents a 26.3 percent increase in historical recharge in the Nueces Basin. When the water rights of the CC/LCC System are not honored, a net average gain of 113,083 ac-ft per year of recharge can be attained. This represents a 34.9 percent increase in historical recharge in the Nueces Basin.

Table ES-3 summarizes the results for the Type 2 structures. With a combined capacity of 380,950 ac-ft (which is 59 percent of the total storage of the Type 1 structures), the Type 2 structures provide an average gain of 61,086 ac-ft per year of recharge if all water rights are honored. This is a 18.9 percent increase over historical recharge in the Nueces Basin. When the water rights of the CC/LCC System are not honored, a net average gain of 112,884 ac-ft per year of recharge can be attained. This represents a 34.8 percent increase in historical recharge. Figure ES-10 compares the cumulative recharge for the two types of structures for the 56-year study period.

Figure ES-11 compares the historical annual recharge with the annual recharge with additional recharge structures for the 10-year drought period from 1947-1956. The additional recharge with the Type 1 structures averages 19,062 ac-ft per year when all water rights are honored and averages of 29,673 ac-ft per year if the water rights of the

Table ES-2
Maximum Storage Capacity and Additional Recharge Potential of Type 1 Recharge Structures

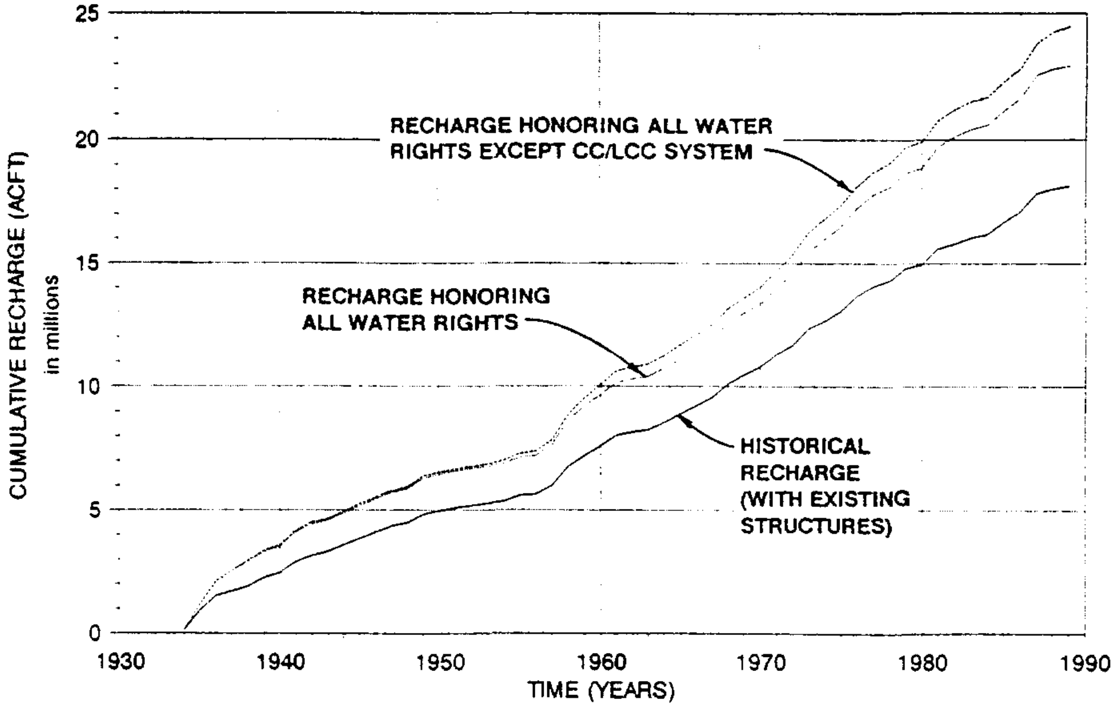
Recharge Area	Reservoirs	Maximum Storage (Ac-Ft)	Historical* Average Annual Recharge (Ac-Ft/Yr)	Additional Recharge with New Structures: Honoring All Water Rights (Ac-Ft/Yr)	Additional Recharge with New Structures: Honoring All Water Rights Except CC/LCC System (Ac-Ft/Yr)
1) Nueces-West Nueces			88,018	41,309	57,510
	Montell	252,300			
2) Frio-Dry Frio			109,136	16,306	19,758
	Upper Dry Frio	60,000			
	Concan	149,000			
3) Sabinal			32,228	12,226	16,794
	Upper Sabinal	93,300			
4) Area between Sabinal and Medina			94,647	15,420	19,021
	Upper Seco	23,000			
	Upper Hondo	47,000			
	Upper Verde	23,000			
Additional Recharge				85,261	113,083
Total Recharge			324,029	409,290	437,112
Percent Increase in Historical Recharge*				26.3%	34.9%

*Historical recharge is adjusted for three existing recharge projects and existing water rights.

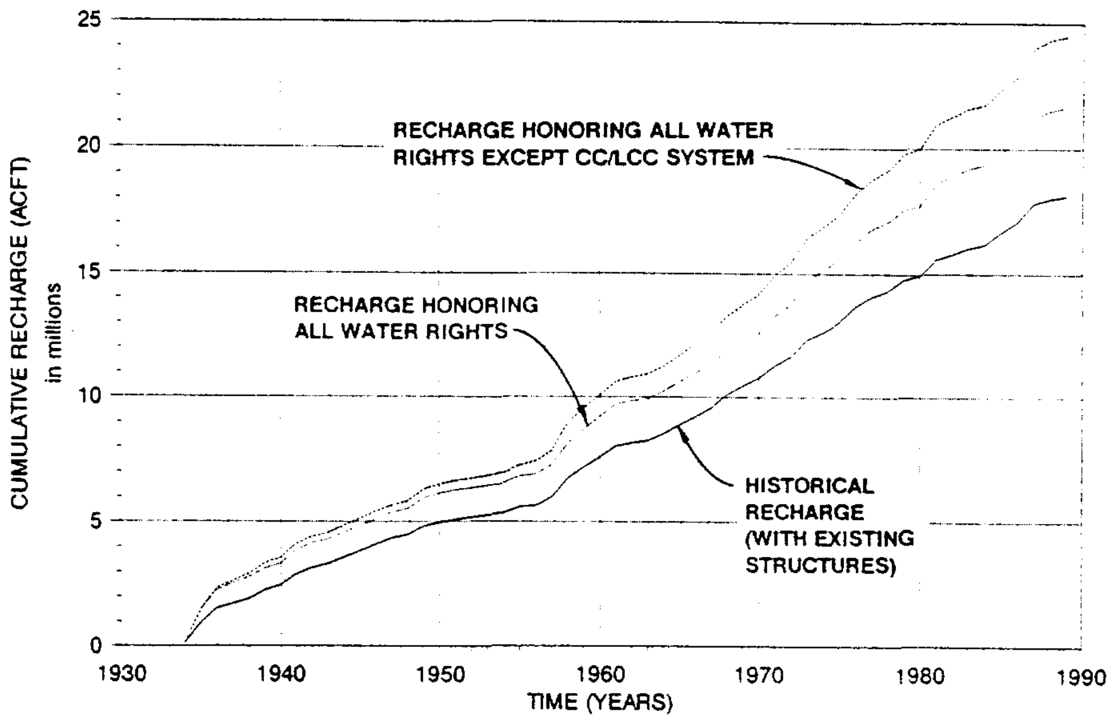
Table ES-3
Maximum Storage Capacity and Additional Recharge Potential of Type 2 Recharge Structures

Recharge Area	Reservoirs	Maximum Storage (Ac-Ft)	Historical* Average Annual Recharge (Ac-Ft/Yr)	Additional Recharge with New Structures	
				Honoring All Water Rights (Ac-Ft/Yr)	Honoring All Water Rights Except CC/LCC System (Ac-Ft/Yr)
1) Nueces-West Nueces			88,018	37,090	55,609
	Indian Creek	165,000			
2) Frio-Dry Frio			109,136	10,828	21,131
	Lower Dry Frio	30,000			
	Lower Frio	50,000			
	Leona	2,930			
	Blanco	6,580			
3) Sabinal			32,228	6,844	17,956
	Lower Sabinal	35,000			
	Little Blanco	2,930			
4) Area between			94,647	6,324	18,188
Sabinal and Medina	Lower Seco	28,000			
	Lower Hondo	28,000			
	Lower Verde	24,000			
	Elm Creek	6,940			
	Quihi Creek	1,570			
Additional Recharge				61,086	112,884
Total Recharge			324,029	385,115	436,913
Percent Increase in Historical Recharge*				18.9%	34.8%

*Historical recharge is adjusted for three existing recharge projects and existing water rights.



TYPE 1 RECHARGE STRUCTURES



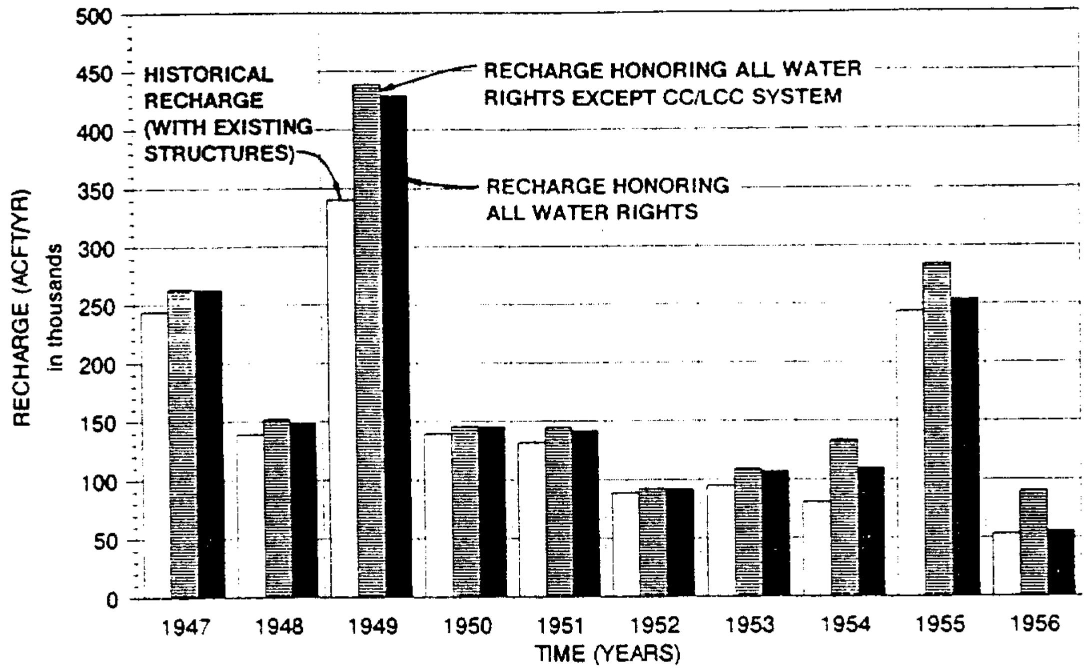
TYPE 2 RECHARGE STRUCTURES

NUECES RIVER BASIN STUDY

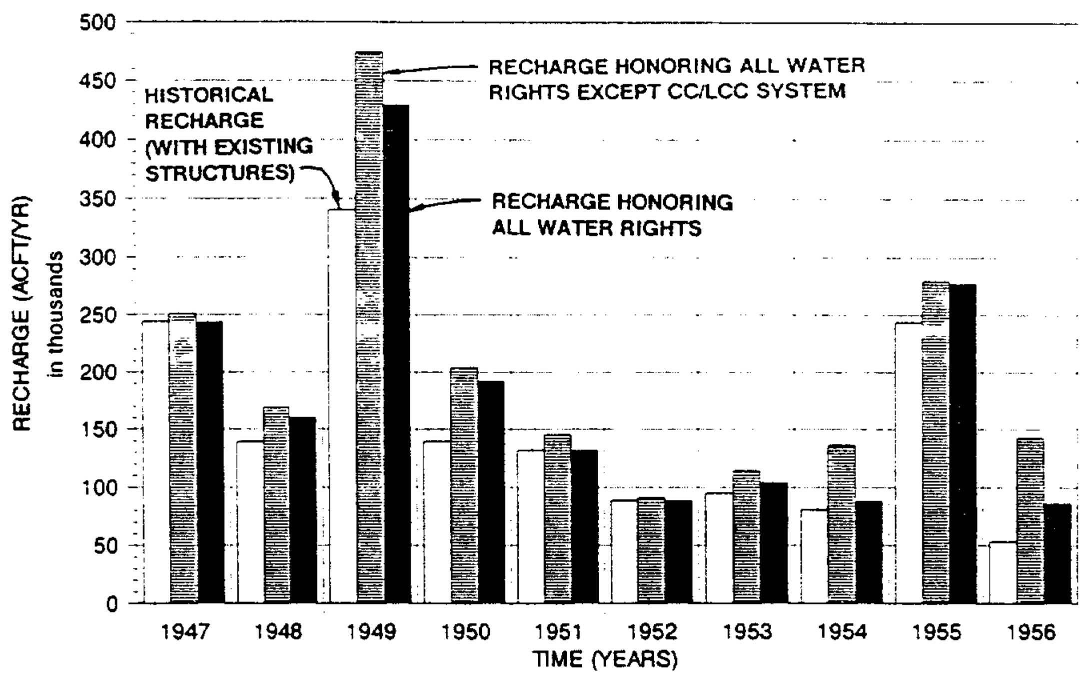
COMPARISONS OF CUMULATIVE EDWARDS AQUIFER RECHARGE WITH ADDITIONAL RECHARGE STRUCTURES

HDR

HDR Engineering, Inc. FIGURE ES-10



TYPE 1 RECHARGE STRUCTURES



TYPE 2 RECHARGE STRUCTURES

NUECES RIVER BASIN STUDY

COMPARISONS OF EDWARDS AQUIFER RECHARGE DURING DROUGHT WITH ADDITIONAL RECHARGE STRUCTURES

HDR

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FIGURE ES-11

CC/LCC System are not honored. This represents a 12.2 and 19.1 percent increase, respectively. For Type 2 structures, recharge for this same 10-year period could be increased by an average of 24,073 ac-ft per year if all water rights are honored and 44,801 ac-ft per year if the water rights of the CC/LCC System are not honored. This represents a 15.5 and 28.8 percent increase, respectively.

It is interesting to note that about half of the increase in recharge for the Type 1 structures comes from the Montell site located on the Nueces River. This is the largest of the recharge projects evaluated and has a maximum storage of 252,300 acre feet, which represents 39 percent of the total storage of the Type 1 recharge reservoirs. For the Type 2 recharge reservoirs, the largest increase in recharge is provided by the Indian Creek site, which is also located on the Nueces River. This site has a maximum capacity of 165,000 acre feet, which represents 43 percent of the total storage of the Type 2 structures and provides between 49 percent and 61 percent of the additional recharge depending on which water rights are honored. For both the Montell and Indian Creek sites, recharge rates which exceed the natural recharge rate of the Nueces River were used in the model. This was done in order to use the full storage potential of these sites. It was assumed that injection wells or diversion to the Dry Frio River would be used to achieve the recharge rates necessary to fully use the water stored in these sites. Further detailed analyses will be necessary for these two sites to determine if recharge in this portion of the aquifer, which is west of the Knippa Gap, will benefit eastern portions of the aquifer or simply enhance spring flows at Leona Springs at Uvalde.

The recharge figures presented herein generally represent a theoretical upper limit of increases in annual recharge if all recharge projects are fully developed. Although it is not likely that all projects will be fully developed, future appropriations of water in watersheds with fully developed projects will be limited. It is likely that further study will show that the actual recharge attainable from these recharge structures will be less than presented herein when considering the economic, environmental, or structural factors. Additionally, the storage capacities of some sites may be limited by geologic or man-made features.

5. Summary of Channel Losses and Long-term Trends in Runoff Characteristics Downstream of Recharge Zone

To determine the effects of the recharge projects on the yield of the CC/LCC System, channel loss rates were calculated for major stream reaches downstream of the recharge zone. The results of these channel loss computations are summarized in Table ES-4 for each of the four major reaches. Channel loss rates for the seven reaches analyzed ranged from a low of 0.36 percent per mile for the Derby to Calliham reach on the Frio River to a high of 0.65 percent per mile for the Uvalde to Asherton reach of the Nueces River. Channel losses computed for the braided reach of the Nueces River averaged 0.43 percent per mile and were within the range of loss rates estimated by the USGS during previous studies. Generally, channel loss rates were higher in aquifer outcrop areas.

Table ES-4
Summary of Channel Losses Downstream of Recharge Zone

River Reach	Reach Length (miles)	Percent of Upstream Flow Lost
Nueces River between Uvalde and Lake Corpus Christi	291.4	84.5
Frio River between Recharge Zone and Choke Canyon Reservoir	173.7	66.3
Frio and Nueces Rivers between Choke Canyon Reservoir and Lake Corpus Christi	63.3	29.7
Nueces River between Lake Corpus Christi and Calallen Dam	35	7.0*

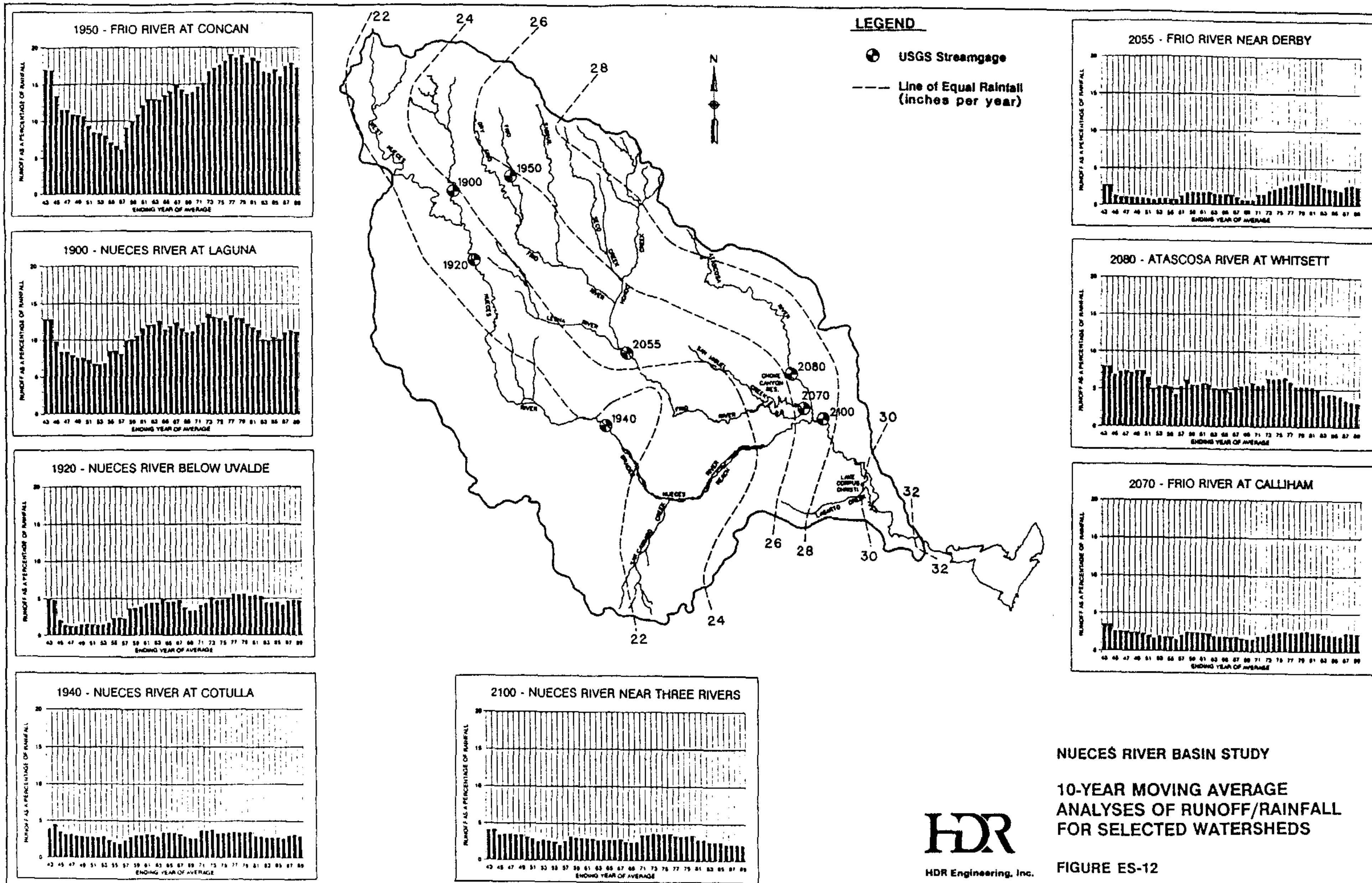
*Represents average water delivery loss rate as determined by several TWDB and USGS investigations.

Channel losses were computed between all control points (gage locations) located downstream of the recharge zone by performing a long-term analysis on each reach for the period of concurrent gage records. Intervening flows arriving at the downstream end of each reach were estimated using a modified SCS curve number procedure and composite monthly precipitation. The percentage of flow at the upstream control point arriving at the downstream control point was computed for each month and tabulated. The final long-term channel loss rate was then computed by averaging the flow volumes from only these months when losses were between 0 percent and 100 percent. Months when losses were calculated to be greater than or equal to 100 percent (i.e., estimated intervening flow exceeds measured downstream flow) and months when no losses were calculated (i.e., measured downstream flow minus intervening flow exceeds measured upstream flow) were not included in the averages as these months represent extreme or impossible conditions which are a result of inaccuracies inherent in estimating monthly runoff for large intervening watersheds on the basis of monthly precipitation records and estimated curve numbers.

Analyses of long-term trends in streamflow were performed to determine if runoff characteristics have been influenced over time by changes in rangeland and agricultural practices in the watershed. Methods used for these analyses have limited accuracy due to the naturally wide variations in rainfall and runoff patterns in a basin the size of the Nueces.

In an attempt to identify trends in selected portions of the basin, 10-year moving average analyses of rainfall and runoff were performed at eight long-term gage locations. Annual rainfall and runoff totals were tabulated and 10-year moving averages calculated for the 56-year period from 1934 through 1989. The results of these analyses are summarized in Figure ES-12, which includes graphs showing runoff expressed as a percentage of rainfall at all eight sites.

A review of Figure ES-12 shows that runoff as a percentage of rainfall for two watersheds (i.e., Atascosa River at Whitsett and Nueces River at Three Rivers) may exhibit downward trends in runoff over the period. A check to see if these apparent trends were statistically significant was performed using annual rainfall and runoff values. As these



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NUECES RIVER BASIN STUDY

10-YEAR MOVING AVERAGE ANALYSES OF RUNOFF/RAINFALL FOR SELECTED WATERSHEDS

FIGURE ES-12

statistical analyses were inconclusive, no adjustments to historical streamflows were included in the model to account for any long-term changes in runoff characteristics.

6. Firm Yield of Choke Canyon Reservoir and Lake Corpus Christi System without Additional Recharge Structures

Reservoir operation studies were performed on the CC/LCC System for both 1990 and 2040 reservoir sediment conditions to determine the firm yield of the system. The firm yield of a reservoir system is defined as the quantity of water which can be reliably diverted year after year from the reservoir system without a shortage. The period of record for this study is the 1934 through 1989 period, which included significant droughts in the 1950's, 1960's, and 1980's. The firm yield of a reservoir system will vary depending on sediment accumulation, operating rules, and, in the case of the CC/LCC System, the location where water is actually diverted. Studies were performed for both 1990 and 2040 reservoir sediment conditions as well as for two sets of system operating rules (i.e., Phases II and IV of the City of Corpus Christi's reservoir operation plan). Estimates of system firm yield reported in this study include the losses associated with delivery of water from Lake Corpus Christi to the Calallen diversion facility. Previous estimates of system firm yield by the U.S. Bureau of Reclamation (USBR) and TWDB have been based on direct diversion of water from Lake Corpus Christi.

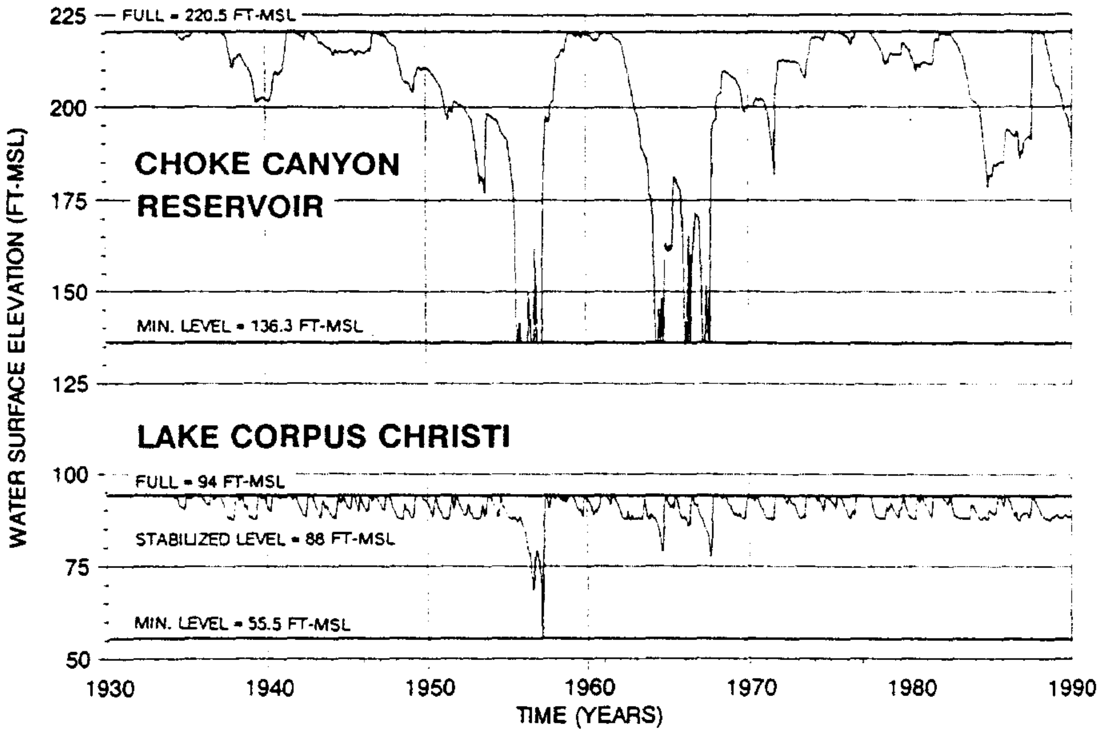
Under the present reservoir operation policy (i.e., Phase II), 2,000 ac-ft are released each month from Choke Canyon Reservoir until the level in Lake Corpus Christi drops to 88 feet-MSL, which is 6 feet below conservation level. At this point, monthly releases from Choke Canyon are increased based on water supply requirements at Lake Corpus Christi sufficient to maintain an operating level of 88 feet-MSL. When the elevation of Choke Canyon Reservoir drops below elevation 155 feet-MSL, releases are reduced and remaining storage in Lake Corpus Christi is depleted. Under the Phase IV operation policy, 2,000 ac-ft are released each month from Choke Canyon Reservoir until the level in Lake Corpus

Christi drops to 76 feet-MSL, which is 18 feet below conservation level. Figure ES-13 shows lake level fluctuations for 1990 sediment conditions for both reservoirs when operated at firm yield demands in accordance with Phase II and IV policies.

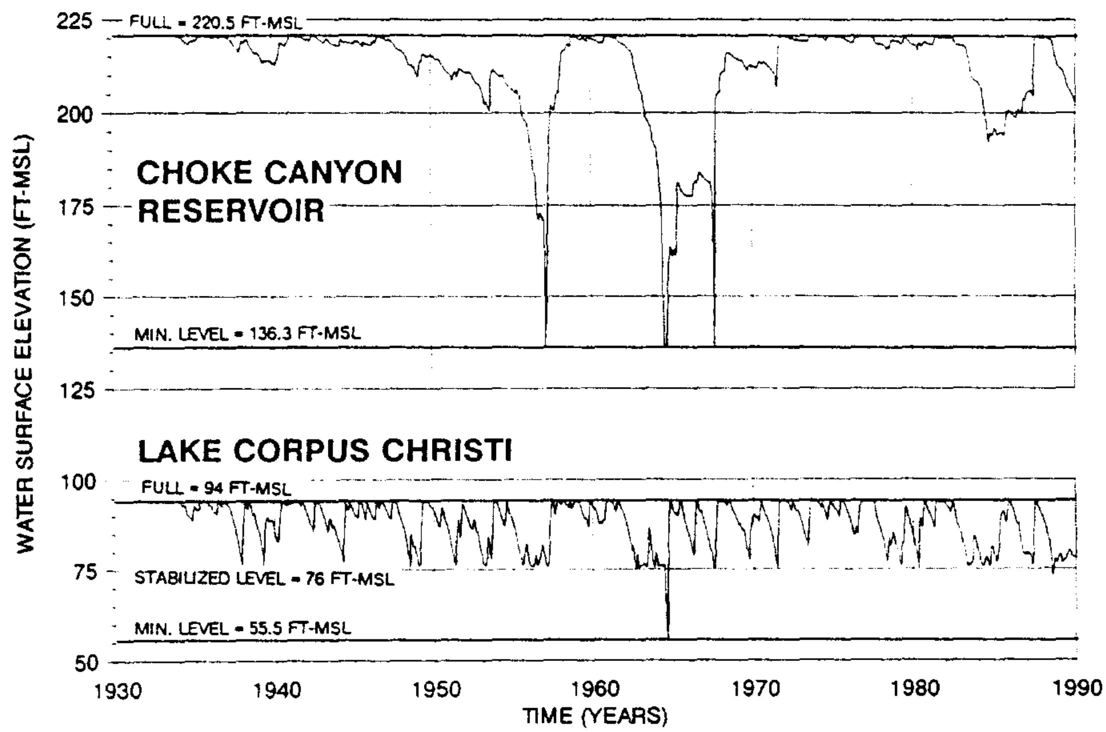
Firm yield analyses were performed considering two cases of water use by upstream water rights. Case 1 included existing upstream water rights diverting at 1988 reported use levels. Case 2 included existing upstream water rights diverting at full permitted authorization. Phase IV policy was analyzed first, considering both Case 1 and Case 2 conditions of upstream use. For Case 1 conditions, the firm yield of the CC/LCC System was determined to be 224,400 ac-ft per year for 1990 sediment conditions and 204,100 ac-ft per year for 2040 sediment conditions. Under Case 2 conditions, the firm yield of the system was reduced by 2.0 percent to 220,000 ac-ft per year for 1990 sediment conditions and by 3.2 percent to 197,500 ac-ft per year for 2040 sediment conditions. The effect of increased usage by existing upstream rights was to reduce the 1990 firm yield by 4,400 ac-ft per year and the 2040 firm yield by 6,600 ac-ft per year.

Firm yield analysis were next performed for the existing Phase II policy with upstream water rights diverting at full permitted authorization (i.e., Case 2 conditions). For 1990 sediment conditions the yield was determined to be 187,800 ac-ft per year, which is 32,200 ac-ft per year or 14.6 percent less than the comparable yield using the Phase IV policy. For 2040 sediment conditions the system yield was determined to be 169,700 ac-ft per year, which is 27,800 ac-ft per year or 14.1 percent less than the comparable yield using the Phase IV policy.

Lake level fluctuations for the entire 56-year period analyzed are shown in Figure ES-13 for both operation policies and show the differences in the timing of the critical drought. Under the Phase IV policy, the critical drought occurred from 1961 through 1964.



PHASE II OPERATION POLICY



PHASE IV OPERATION POLICY

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CC/LCC SYSTEM 1990 FIRM YIELD WATER SURFACE ELEVATION TRACES

FIGURE ES-13

However, with the Phase II policy in place, the critical drought occurred during the 1947 through 1956 period.

Permanent operating rules defining the water requirements for the Nueces Estuary have not been adopted by the Texas Water Commission (TWC). These rules are anticipated to be finalized sometime in 1991. However, a worst case scenario of providing at least 151,000 ac-ft per year to the estuary of return flows, spills or releases from Lake Corpus Christi was analyzed without regard to the release abeyance provisions in the interim TWC order issued August 10, 1990. The results of these analyses are summarized in Table ES-5, which shows that the yield would be reduced by about 25 percent for both 1990 and 2040 sediment conditions if the full 151,000 ac-ft were released each year without regard to the release abeyance provisions in the interim order.

The year 2010 firm yield of the CC/LCC System is approximately 184,100 ac-ft per year under Phase II policy with full diversions by upstream rights. This yield is about 64,900 ac-ft per year or 26.1 percent less than the 2010 firm yield of 249,000 ac-ft per year as estimated by the Bureau of Reclamation (Bureau). (The original Bureau yield of 252,000 ac-ft per year has recently been revised to 249,000 ac-ft per year based on refined yield studies by the Bureau.) Although a detailed analysis of factors contributing to the difference between the Bureau's yield and those calculated in this report has not been performed, one major difference is that the Bureau calculates yield at the lakes and does not include channel losses affecting water released from both Choke Canyon Reservoir and Lake Corpus Christi downstream to the Calallen Diversion Dam. This study calculates system yield based on water delivered to Calallen. Another significant difference between this study and the Bureau's yield estimate is the conservation capacity of Lake Corpus Christi. Results of a recent sediment survey indicate that by the year 2010, Lake Corpus Christi will have a capacity of about 212,353 ac-ft or 47,647 ac-ft less than the capacity used by the Bureau in their studies.

Table ES-5
Firm Yield of Choke Canyon Reservoir and Lake Corpus Christi System with No Additional Recharge Structures

	System Firm Yield	
	1990 Sediment (Ac-Ft/Year)	2040 Sediment (Ac-Ft/Year)
I. Without Full Release of 151,000 Ac-Ft to Estuary*		
A) Phase IV Policy		
Case 1) Upstream Water Rights Diverting at 1988 Use Levels	224,400	204,100
Case 2) Upstream Water Rights Diverting at Full Authorization	220,000	197,500
B) Phase II Policy		
Case 2) Upstream Water Rights Diverting at Full Authorization	187,800	169,700
II. With Full Release of 151,000 Ac-Ft to Estuary**		
A) Phase IV Policy		
Case 1) Upstream Water Rights Diverting at 1988 Use Levels	171,700	152,700
Case 2) Upstream Water Rights Diverting at Full Authorization	166,300	147,300
B) Phase II Policy		
Case 2) Upstream Water Rights Diverting at Full Authorization	122,400	107,100

*Assumes that only 47% of water diverted is returned to the estuary. For the six yields shown, this would vary from a minimum of 79,800 ac-ft per year to a maximum of 105,500 ac-ft per year of return flows.

**Assumes 47% of water diverted contributes to return flows with balance of 151,000 ac-ft per year coming first from spills, if available, and any remainder coming from releases.

7. Firm Yield of Choke Canyon Reservoir and Lake Corpus Christi System with Additional Recharge Structures

Reservoir operation studies were performed on the CC/LCC System for 1990 sediment conditions to determine the impacts of the two types of recharge structures on reservoir inflows, system yield, average lake levels, and required releases to the estuary. The senior rights of the Choke Canyon/Lake Corpus Christi System were not honored. Phase IV operation policy for the CC/LCC System was used and upstream water rights were diverted at their full authorization subject to water availability.

Type I recharge structures were the first group analyzed. These are the seven reservoirs located upstream of the recharge zone which would catch water and then gradually release it at a rate that allows maximum recharge efficiency. Reservoir operation studies of the CC/LCC System with all seven Type 1 structures in place show that inflows to the CC/LCC System would be reduced on the average 37,800 ac-ft per year or 5.0 percent, and the 1990 system yield would decrease 3,900 ac-ft per year to 216,100 ac-ft per year. This is a decrease of 1.8 percent of the 1990 yield without additional recharge structures. A comparison of average lake levels with and without the Type 1 recharge reservoirs in place indicates that the average level of Lake Corpus Christi will be reduced by 0.06 feet. At Choke Canyon Reservoir, the average reduction is 0.52 feet.

Type 2 reservoirs were the second group of recharge structures analyzed. These are the twelve reservoirs located within the recharge zone which, after filling, immediately recharge the aquifer. CC/LCC System yield analysis with Type 2 structures in place shows that inflows to CC/LCC System would be reduced on the average 40,700 ac-ft per year or 5.4 percent, and the 1990 system yield would decrease 5,800 ac-ft per year to 214,200 ac-ft per year. This is a decrease of 2.6 percent of the 1990 yield without additional recharge structures. A comparison of average lake levels with and without the Type 2 recharge reservoirs in place indicates that the average level of Lake Corpus Christi will be reduced by 0.03 feet. At Choke Canyon Reservoir, the average reduction is 0.41 feet. A summary of the firm yield analyses of the CC/LCC System with and without additional recharge structures is given in Table ES-6.

Additional analyses were performed to determine the impact the recharge structures would have on the ability of the CC/LCC System to meet the 151,000 ac-ft requirement for inflows to the Nueces Estuary. The results of these analyses indicated that, under Phase IV operation policy, spills from Lake Corpus Christi were affected within the 151,000 ac-ft criteria in only six out of the 56 years analyzed. The reduced spill volume, which would have to be made up from additional reservoir releases, averaged 175 ac-ft per year for Type 1 structures and 206 ac-ft per year for Type 2 structures. Although these analyses showed that the recharge projects will not significantly impact the existing 151,000 ac-ft estuary requirement, an additional analysis should be performed when final operating rules are established by the TWC.

Table ES-6
Firm Yield of Choke Canyon Reservoir and Lake Corpus Christi System with Additional Recharge Structures

	1990 System Firm Yield* (Ac-Ft/Year)	% Decrease from Baseline
Baseline - No Additional Recharge Structures	220,000	---
Case 1) With Seven Type 1 Recharge Structures	216,100	1.8
Case 2) With Twelve Type 2 Recharge Structures	214,200	2.6

*Firm yield for Phase IV policy as calculated at Calallen Dam without regard to meeting 151,000 ac-ft release for estuary. All runs assume upstream water rights are diverting at full authorization subject to water availability.

8. Comparison of CC/LCC System Yield with Projected Water Demands

In the 12-county Choke Canyon/Lake Corpus Christi service area, population in 1980 was 502,058 and combined municipal and industrial (i.e., manufacturing) water use from ground and surface water sources was 146,615 ac-ft. The twelve counties in this service area include the four coastal counties of Aransas, San Patricio, Nueces, and Kleberg and the eight inland counties of Atascosa, Bee, Refugio, Live Oak, McMullen, Duval, Jim Wells, and Brooks. According to estimates prepared by the Texas Water Development Board, population in these counties is projected to increase to between 615,583 and 633,509 by 2000; to between 755,184 and 837,112 by 2020; and to between 913,637 and 1,051,681 by 2040. Projected water requirements (with conservation), considering only municipal and industrial needs, range between 174,000 and 183,000 acre-feet per year for the year 2000. Projected water requirements for 2020 range between 196,000 and 226,000 acre-feet per year and, for 2040, range between 235,000 and 283,000 acre-feet per year.

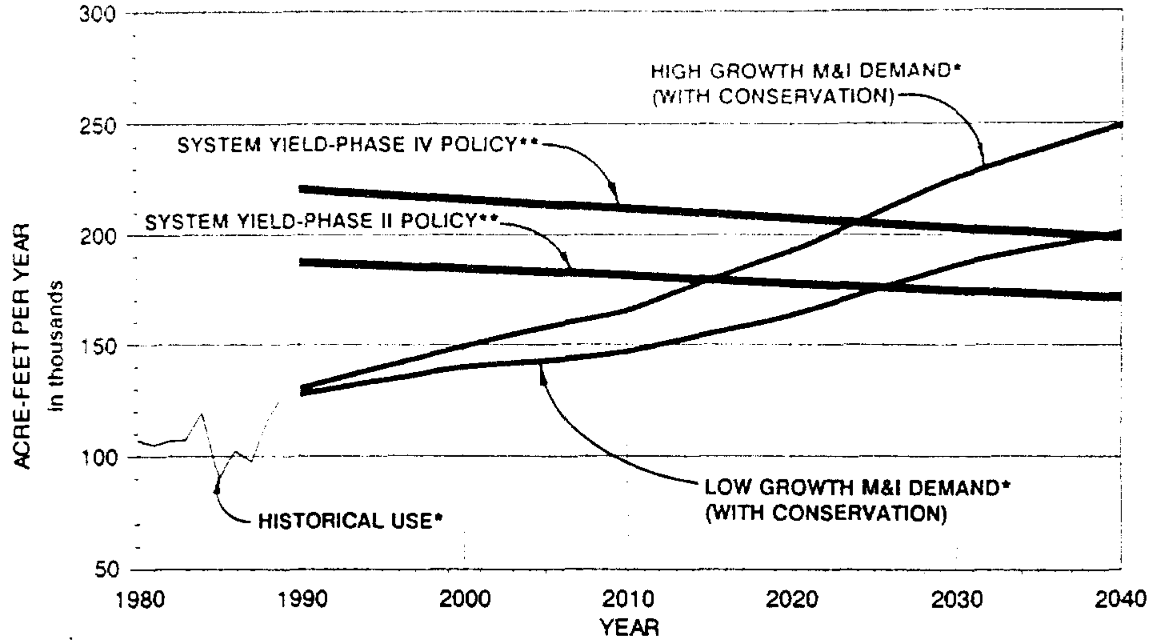
Presently, not all municipal and industrial (M&I) water users in the 12-county service area are supplied from the CC/LCC System. The latest water use data from the TWDB indicates that in 1985 about 34,000 ac-ft of demand in the 12-county area was met by water sources other than the CC/LCC System. Approximately 74 percent of this demand, or 25,000 ac-ft, was met from ground water sources. Although it is impossible to accurately predict when, and if, other entities will be supplied by the CC/LCC System, two scenarios have been prepared for the purpose of estimating the potential impact on system demands. These two scenarios include a best case (with respect to minimizing system demand) and a probable case. The best case scenario assumes that 34,000 ac-ft of the 12-county area demand will continue to be supplied from ground and surface water sources other than the CC/LCC System throughout the 1990 to 2040 period. The probable case scenario assumes that use of the 34,000 ac-ft will gradually decline as reliance on ground water sources is reduced so that, by the year 2020, only 17,000 ac-ft per year of demand will be met from sources other than the CC/LCC System. Table ES-7 shows the projected M&I demands for the CC/LCC System for both scenarios for the 1990 through 2040 period for both low and high growth rates.

Table ES-7
Projected M & I Demands for CC/LCC System

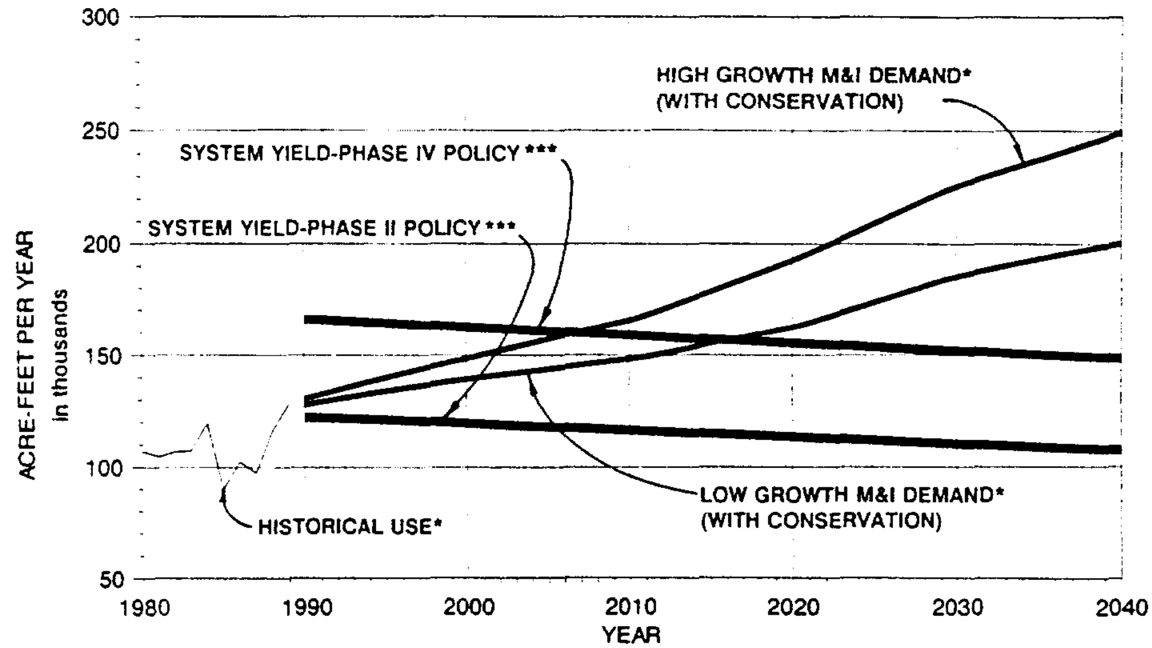
Year	Total 12-County M&I Demand Ac-Ft/Yr	Demand Met From Other Sources Ac-Ft/Yr	Demand on CC/LCC System Ac-Ft/Yr	Percent of 12-County M&I Demand on CC/LCC System
I. Best Case Scenario				
Low Growth				
1990	162,446	34,000	128,446	79
2000	174,082	34,000	140,082	80
2010	181,458	34,000	147,458	81
2020	196,355	34,000	162,355	83
2030	219,705	34,000	185,705	85
2040	234,710	34,000	200,710	86
High Growth				
1990	164,194	34,000	130,194	79
2000	183,459	34,000	149,459	81
2010	199,092	34,000	165,092	83
2020	226,110	34,000	192,110	85
2030	259,817	34,000	225,817	87
2040	282,794	34,000	248,794	88
II. Probable Case Scenario				
Low Growth				
1990	162,446	31,500	130,946	81
2000	174,082	26,500	147,582	85
2010	181,458	21,500	159,958	88
2020	196,355	17,000	179,355	91
2030	219,705	17,000	202,705	92
2040	234,710	17,000	217,710	93
High Growth				
1990	164,194	31,500	132,694	81
2000	183,459	26,500	156,959	86
2010	199,092	21,500	177,592	89
2020	226,110	17,000	209,110	92
2030	259,817	17,000	242,817	93
2040	282,794	17,000	265,794	94

Comparisons of projected water demands with system yield estimates are presented in Figure ES-14 for the best case demand scenario and in Figure ES-15 for the probable case demand scenario. The upper graph on Figure ES-14 shows that for the best case scenario, if no additional recharge structures are constructed, the yield of the system (without considering releases to the estuary) will meet the service area needs until sometime between the years 2014 and 2025 under the existing Phase II operation policy and until between 2024 and 2039 under Phase IV operation policy. Phase II operation policy is the City of Corpus Christi's present system operation policy. Under this policy, the level of Lake Corpus Christi is generally stabilized at elevation 88 feet msl. Under the City's Phase IV operation policy, the level of Lake Corpus Christi is not stabilized until the lake level drops to elevation 76 feet msl. The bottom graph on Figure ES-14 shows that if an absolute requirement for 151,000 ac-ft per year of estuary inflows is met, without suspending releases during drought conditions, then the yield of the system is presently not adequate to meet demands under Phase II operation policy. The firm yield under Phase IV operation policy will meet the service area needs until sometime between 2008 and 2016. Under the best case demand scenario, between 3,200 and 141,700 ac-ft per year of additional water will be needed by the year 2040, depending on the growth rate, system operation policy, and the final impact of permanent operating rules for estuary releases on system yield.

The upper graph on Figure ES-15 shows that for the probable case demand scenario, the yield of the system (without considering releases to the estuary) will meet the service area needs until sometime between the years 2010 and 2018 under Phase II operation policy and until between 2020 and 2030 under Phase IV operation policy. The bottom graph on Figure ES-15 shows that if an absolute requirement for 151,000 ac-ft per year of estuary inflows is met, then the yield of the system is presently not adequate to meet demands under



CC/LCC SYSTEM DEMANDS AND FIRM YIELD WITHOUT FULL RELEASE FOR ESTUARY**



CC/LCC SYSTEM DEMANDS AND FIRM YIELD WITH FULL RELEASE FOR ESTUARY***

*M&I Demands are for best case conditions which assume that 34,000 ac-ft per year of M&I demand for the 12-county area will be met from sources other than the CC/LCC System. Historical use from July 1984 through February 1985 (and for a period of time thereafter) was limited by severe drought conservation measures.

**Assumes that only spills and wastewater return flows contribute to estuary inflows. No releases are made to the estuary.

***Assumes that releases are made as needed to provide 151,000 ac-ft per year to the estuary after crediting spills and wastewater return flows. No drought contingency relief provision is included for estuary releases.

NUECES RIVER BASIN STUDY

COMPARISONS OF BEST CASE CC/LCC SYSTEM DEMANDS WITH SYSTEM FIRM YIELD

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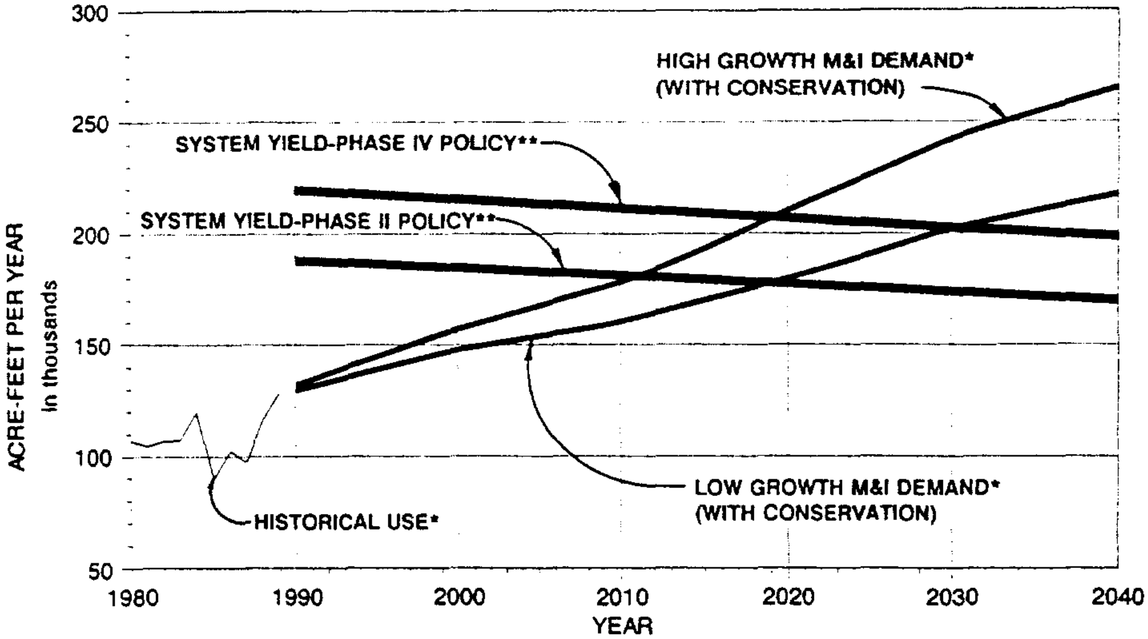
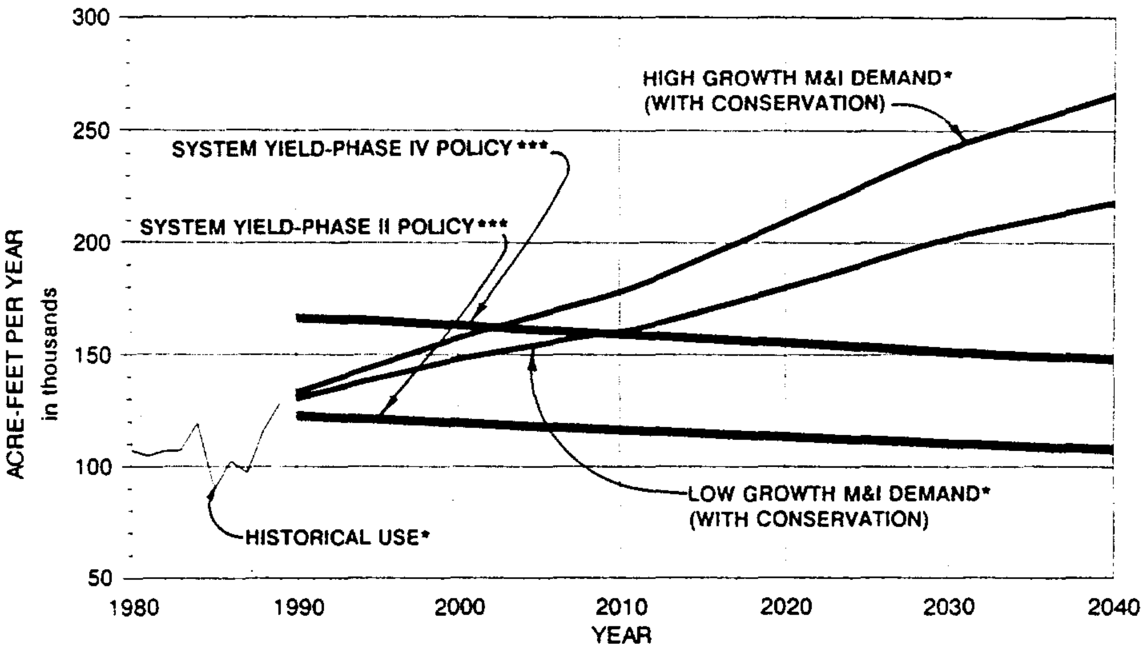
FIGURE ES-14



CC/LCC SYSTEM DEMANDS AND FIRM YIELD WITHOUT FULL RELEASE FOR ESTUARY**



CC/LCC SYSTEM DEMANDS AND FIRM YIELD WITH FULL RELEASE FOR ESTUARY***

*M&I Demands are for probable case conditions which assume that by the year 2020, 17,000 ac-ft per year of M&I demand for the 12-county area will be met from sources other than the CC/LCC System. Historical use from July 1984 through February 1985 (and for a period of time thereafter) was limited by severe drought conservation measures.

**Assumes that only spills and wastewater return flows contribute to estuary inflows. No releases are made to the estuary.

***Assumes that releases are made as needed to provide 151,000 ac-ft per year to the estuary after crediting spills and wastewater return flows. No drought contingency relief provision is included for estuary releases.

NUECES RIVER BASIN STUDY

COMPARISONS OF PROBABLE CASE CC/LCC SYSTEM DEMANDS WITH SYSTEM FIRM YIELD

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FIGURE ES-15

Phase II operation policy. The firm yield under Phase IV operation policy will meet the service area needs until sometime between 2002 and 2009. Under the probable case scenario, between 20,200 and 158,700 ac-ft per year of additional water will be needed by the year 2040, depending on the growth rate, system operation policy and the final impact of permanent operating rules for estuary releases on system yield.

In order to meet the projected water demands of the CC/LCC service area, additional water supplies will be needed. The timing of the development of the additional supplies will vary depending on growth rates, the number of new customers, the final TWC bay release requirements, system operation policy, and whether or not additional recharge structures are constructed. Additional water supply alternatives available to the 12-county service area include the following:

* Construction of a pipeline from Choke Canyon Reservoir to either Lake Corpus Christi or the O.N. Stevens Water Treatment Plant at Calallen to avoid natural channel losses which are significant under existing operating conditions;

* Construction of a pipeline from Lake Corpus Christi to the O.N. Stevens Water Treatment Plant to avoid natural channel losses (this pipeline could also serve as a portion of the pipeline to Choke Canyon);

* Construction of a diversion dam, pump station, and pipeline from a point on the Nueces River (either near Simmons or below Three Rivers) to pump flows into Choke Canyon Reservoir at those times when Lake Corpus Christi is above a specified level and Choke Canyon is below conservation level;

* Construction of a pump station and pipeline from near Lake Texana to either a new treatment plant located in the eastern portion of the service area or to the O.N. Stevens Water Treatment Plant; or

* Construction of a diversion dam, pump station, off-channel balancing reservoir, and pipeline from the Guadalupe River (and/or San Antonio River) to either a new treatment plant located in the eastern portion of the service area or to the O.N. Stevens Water Treatment Plant. (This project could serve as the first phase of the pipeline to Lake Texana.)

9. Impact of Additional Recharge Projects on Inflows to the Nueces Estuary

According to studies of the Nueces Estuary performed by the Texas Water Development Board, approximately 87 percent of historical fresh water inflows were contributed by water which originated upstream of Lake Corpus Christi. To determine the impacts of the recharge structures on inflows to the estuary, a comparison of average annual spills at Lake Corpus Christi (with full use of the system yield) was made for the 56-year study period. As shown in Table ES-7, spills at Lake Corpus Christi under 1990 sediment conditions and Phase IV operations averaged 288,000 ac-ft per year without any additional recharge structures. With all seven Type 1 structures in place, annual spills were reduced by 15,800 ac-ft per year or 5.5 percent on the average. The year in which the largest impact on the total spill volume occurred was 1935 when spills were reduced by 137,500 ac-ft or 6.0 percent. With all twelve Type 2 structures in place (and no Type 1 structures), annual spills were reduced by 15,200 ac-ft per year or 5.3 percent on the average. The year in which the largest impact on the total spill volume occurred was 1935 when spills were reduced by 136,800 ac-ft or 6.0 percent.

A comparison of the number of months with spills at Lake Corpus Christi was made with and without the recharge structures in place. For 1990 sediment conditions, Phase IV operation policy, and a firm yield demand of 220,000 ac-ft per year being diverted from the system, Lake Corpus Christi spills in 117 of the total 672 months analysed or 17.4 percent of the months. When the same analysis is performed with either the Type 1 or Type 2 recharge structures in place, Lake Corpus Christi spills in 112 or 113 of the total 672 months or approximately 16.7 percent of the months. This represents approximately a 4 percent reduction in the number of spill months.

Table ES-7 Reduced Inflow to Corpus Christi Bay System with Additional Recharge Structures			
	1990 System Spills (Ac-Ft/Year)	**Decrease from Baseline (Ac-Ft/Yr)**	**% Decrease from Baseline**
Baseline - No Additional Recharge Structures	288,000	----	----
Case 1) With Seven Type 1 Recharge Structures	272,200	15,800	5.5
Case 2) With Twelve Type 2 Recharge Structures	272,800	15,200	5.3

10. Conclusions

Significant study findings and conclusions are as follows:

- Historical recharge to the Nueces River Basin portion of the Edwards Aquifer can be increased by an average of about 85,300 ac-ft per year if all seven Type 1 recharge structures are constructed and all water rights are honored. This represents an increase of about 26.3 percent in the historical average recharge to the Nueces River Basin portion of the Edwards Aquifer from surface water sources. Recharge during the 10-year drought period from 1947 through 1956 could be increased by about 19,100 ac-ft per year or 12.3 percent of the historical average during this 10-year period.

- Recharge with all twelve Type 2 recharge structures in place can be increased on the average by about 61,100 ac-ft per year or 18.9 percent if all water rights are honored. For the 1947-1956 drought period, recharge could be increased by about 24,100 ac-ft per year or 15.5 percent.

- The recharge estimates in this report represent a theoretical maximum and are subject to significant reductions due to likely economic, environmental, structural, and political limitations on more detailed review.

- With no additional recharge structures in place, the firm yield of the CC/LCC System under Phase IV operating policy is 220,000 ac-ft per year for 1990 conditions and 197,500 ac-ft per year for 2040 conditions. These yields are based on existing water rights diverting at full authorization and do not consider the full release of 151,000 ac-ft per year to the Nueces Estuary. If system releases needed to insure 151,000 ac-ft of annual estuarine inflows are made, without abeyance provisions for drought conditions, then the 1990 firm yield is 166,300 ac-ft per year and the 2040 firm yield is 147,300 ac-ft per year.

- With no additional recharge structures in place, the firm yield of the CC/LCC System under Phase II operating policy is 187,800 ac-ft per year for 1990 conditions and 169,700 ac-ft per year for 2040 conditions. These yields are based on existing water rights diverting at full authorization and do not consider the full release of 151,000 ac-ft per year to the Nueces Estuary. If system releases needed to insure 151,000 ac-ft of annual estuarine inflows are made, without abeyance provisions for drought conditions, then the 1990 firm yield is 122,400 ac-ft per year and the 2040 firm yield is 107,100 ac-ft per year.

- The 1990 firm yield of the CC/LCC System would be reduced by up to 3,900 ac-ft per year with the implementation of all seven Type 1 recharge structures, if these structures were operated not to honor the water rights of the CC/LCC System.

* The 1990 firm yield of the CC/LCC System would be reduced by up to 5,800 ac-ft per year with the implementation of all twelve Type 2 structures, if these structures were operated not to honor the water rights of the CC/LCC System.

* The firm yield of the CC/LCC System is not adequate to meet the system demands over the next 50 years.

* The City of Corpus Christi will need to develop an additional water supply to supplement the yield of the CC/LCC System within the next several decades depending on growth rates, the number of new customers, reservoir operation policy, construction of additional recharge projects, and the impact of the final TWC operating rules on the Nueces Estuary.

* If fully implemented, the Type 1 recharge structures will reduce inflows to the Nueces Estuary by an average of about 15,800 ac-ft per year. The construction of all Type 2 recharge structures will reduce inflows by about 15,200 ac-ft per year. These figures represent between 5.3 and 5.5 percent of the average annual spill volume at Lake Corpus without recharge projects. The average number of spill events will be reduced by about 4 percent with either type of recharge structures.

* If all seven Type 1 recharge structures are implemented, average inflows to the CC/LCC System will be reduced by 37,800 ac-ft per year or 5.0 percent. Average reservoir water levels at Choke Canyon Reservoir would be reduced by 0.52 feet and at Lake Corpus Christi by 0.06 feet.

* If all twelve Type 2 recharge structures are implemented, average inflows to the CC/LCC system will be reduced by 40,700 ac-ft per year or 5.4 percent. Average reservoir water levels at Choke Canyon Reservoir would be reduced by 0.41 feet and at Lake Corpus Christi by 0.03 feet.

* Methods used by the USGS to develop annual estimates of recharge to the Edwards Aquifer significantly over-estimate recharge in wet years.

11. Recommendations

The findings of this study indicate that recharge to the Edwards can be substantially enhanced by the construction of additional recharge structures. In order to determine whether these projects are truly feasible and to quantify potential benefits to well yields and springflows, the following additional studies are recommended:

1) Benefit/cost analyses of individual recharge projects should be performed considering environmental, geologic, and structural feasibility with costs and environmental impacts compared to other potential water supply projects;

2) The Texas Water Development Board model of the Edwards Aquifer should be updated to work on a monthly (rather than annual) time step. The model should then be used to evaluate the various recharge options to determine benefits to well yields and springflows;

3) Depending on favorable results from Item 2, the TWDB model and the recharge portion of the model developed in this study should be combined into one model to further evaluate whether additional benefits could be obtained by adopting a delayed release policy for the Type 1 reservoirs. Under this type of policy, reservoir releases could be tied to aquifer levels and contribute recharge during drought periods when it is needed the most;

4) The interim TWC order should be evaluated to determine impacts on firm yield of CC/LCC System and inflows to the Nueces Estuary;

5) A water supply alternatives study should be undertaken by the City of Corpus Christi to determine the most feasible and economical alternatives to meet the long term needs of the CC/LCC service area; and

6) A new recharge model of the Edwards Aquifer should be developed which combines appropriate elements of the USGS and HDR recharge procedures.