

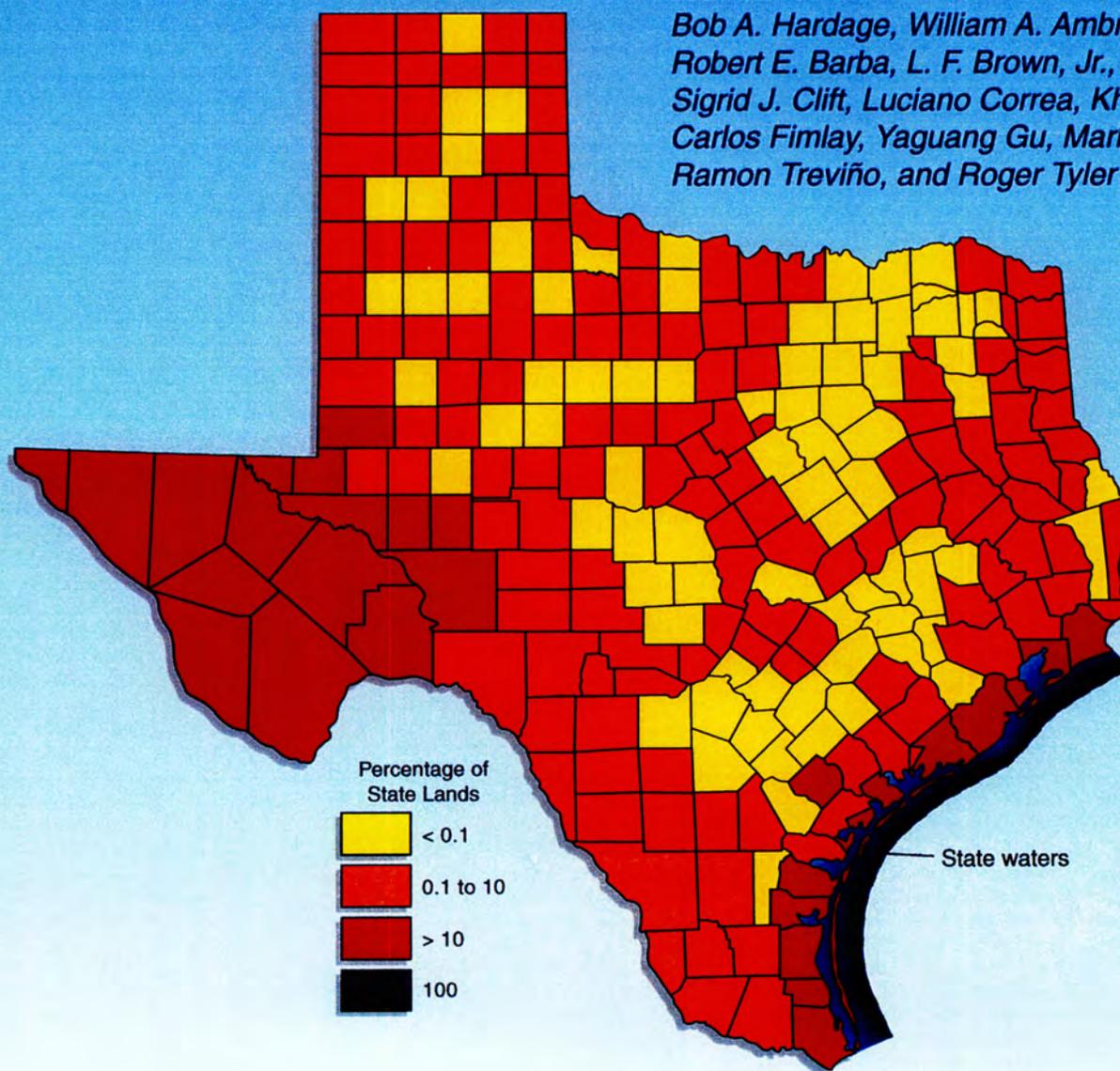
PROJECT STARR

STATE OF TEXAS ADVANCED OIL AND GAS RESOURCE RECOVERY

Progress Report

Researchers

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Robert E. Barba, L. F. Brown, Jr., Jaime Castillo,
Sigrid J. Clift, Luciano Correa, Khaled Fouad,
Carlos Fimlay, Yaguang Gu, Mark H. Holtz,
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Bureau of Economic Geology

Scott W. Tinker, Director

The University of Texas at Austin

Austin, Texas 78713-8924



August 2000

P R O J E C T S T A R R

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EXECUTIVE SUMMARY

The objective of the State of Texas Advanced Resource Recovery program, Project STARR, is to increase royalty income to the Permanent School Fund through the drilling of profitable wells on State lands.

The Bureau of Economic Geology (Bureau) receives \$450,000 per year from the State to pay salaries of Bureau researchers involved in project STARR who analyze State lands properties and databases and then advise operators how to increase production. The State requires program STARR to be revenue positive; that is, the Bureau has to cause an amount of new royalty revenue to flow into the Permanent School Fund that exceeds the \$900,000 that is appropriated to the program every 2 years by the Legislature. This report summarizes the STARR studies that have been done since the inception of the program and documents that in the 2-year period since the last STARR report, the program is revenue positive by a factor of 2.7.

The term *proved oil reserves* refers to oil that will be produced using currently deployed technology. On State Lands, proved oil reserves total 270 million barrels (MMbbl), which is only 8 percent of the 3.43 billion barrels (Bbbl) of oil that is projected to remain across these properties at reservoir abandonment (Holtz and Garrett, 1997). Of this 3.43 Bbbl, 1.6 Bbbl is mobile oil that will not be recovered unless advanced geological, geophysical, and engineering technologies are applied to State Lands reservoirs. This potentially recoverable amount (1.6 Bbbl) nearly equals the cumulative production on State Lands.

A similar picture emerges for natural gas in Texas State Lands fields. Cumulative gas production on State Lands is 10 trillion cubic feet (Tcf) (Holtz and Garrett, 1997). The amount of natural gas remaining in the largest State Lands gas reservoirs is estimated to be another 10 Tcf. The amount of natural gas projected to remain unrecovered at reservoir abandonment using currently deployed technology will almost equal the amount of gas produced to date. With regard

to in-place volumes of oil and gas, State Lands reservoirs are nowhere near depletion, but new technologies must be applied to extract these hydrocarbons.

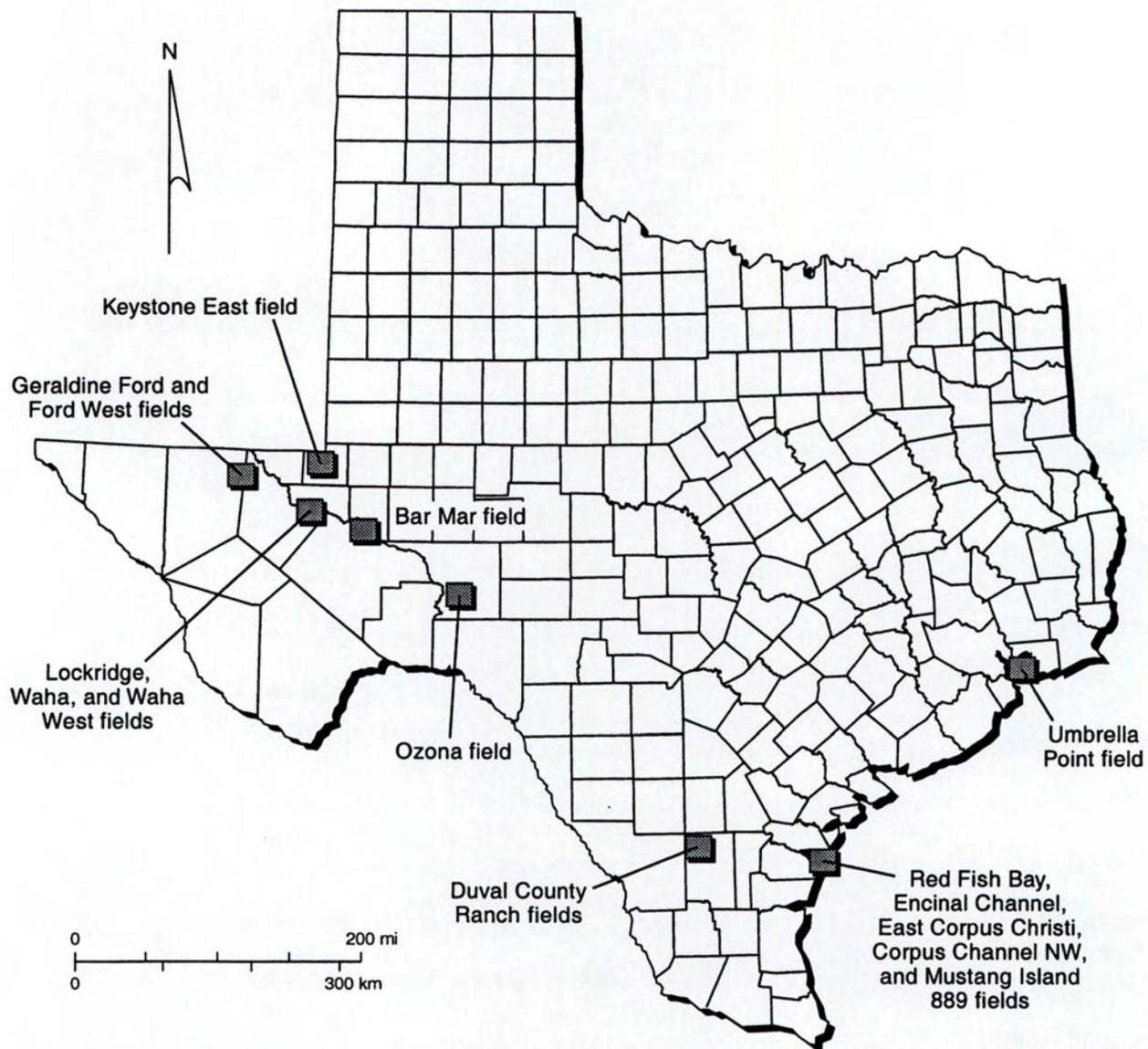
With funding from the State of Texas and database support from the General Land Office and the Railroad Commission of Texas, Project STARR is designed to capture a substantial portion of the large volume of unrecovered oil and gas remaining in State Lands fields. Fifteen State Lands fields have undergone, or are undergoing, characterization and extended development in collaboration with Texas operators under the auspices of this program. Optimization of oil and gas recovery strategies has resulted in the characterization and deployment of advanced recovery technologies in several key reservoirs and in the transfer of new concepts and approaches to recovery optimization to State Lands operators. Detailed geologic, geophysical, and engineering characterization of reservoir systems has identified untapped and bypassed reservoir compartments and zones of remaining oil and gas and allowed optimized recovery strategies, such as step-out wells, well deepening, recompletions, targeted infill drilling, injection profile modification, and waterflood optimization, to be designed. These actions have added to the recoverable oil and gas reserve base remaining on State Lands.

Project STARR has recommended 58 infill wells, 56 recompletions, and 4 step-out wells over the project's 5-year duration (Bureau of Economic Geology, 1996; Tyler and others, 1998; Table 2 of this report). To date, at least 41 infill wells and 29 recompletions have been drilled on State Lands on the basis of STARR recommendations, with these actions creating a total royalty revenue to the Texas Permanent School Fund in the 2 years since the last STARR report (Tyler and others, 1998) of \$2.4 million. The total future revenue to be generated in the State of Texas from the additional oil and gas reserves developed in Project STARR to date should exceed \$88.9 million.

INTRODUCTION

Revenue income to the Permanent School Fund is derived largely from oil and gas royalties from Texas State Lands. However, oil and gas royalty income has declined even though a large hydrocarbon resource base remains on State Lands. In fact, State Lands fields contain more oil and gas than has been recovered over the decades-long history of State Lands production. Rather than being unattainable, a large volume of this remaining oil and gas is recoverable through improved scientific understanding and strategic, targeted deployment of advanced recovery technologies. Advanced technology has historically been the realm of major oil and gas companies, but many large companies in their pursuit of economies of scale have abandoned development of mature Texas oil and gas resources. The departure of these large operators has created opportunities for the remaining producers of State Lands fields. Major companies, who suffer from staff shortages, and independents who have no advanced research and development capabilities are requesting reservoir characterization assistance from the State of Texas Advanced Oil and Gas Resource Recovery Initiative (Project STARR).

The Bureau of Economic Geology, The University of Texas at Austin, with funding from the State of Texas and database support from the General Land Office and the Railroad Commission of Texas, strives to provide this requested technical support. Opportunities for increased production have been identified and, with the support of allied producers, are being drilled. Project STARR has one major goal—increased royalty income to the Permanent School Fund through the drilling of profitable wells. To date, 15 fields have been chosen for assessment: Ozona, Geraldine Ford, Ford West, Lockridge, Waha, Waha West, Bar Mar, Keystone East, Umbrella Point, Red Fish Bay, Duval County Ranch, Corpus Christi East, Corpus Channel NW, Encinal Channel, and Mustang Island 889 (fig. 1). Fourteen Texas operators have been, or are, involved in Project STARR: Bass Enterprises, Conoco, Hallwood Energy, Hanson Corporation, Killam Oil, Mobil (now ExxonMobil), Panaco, Inc., Pi Energy, Pioneer Natural Resources, Royal, Sabco, Shell,



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Figure 1. Map showing Project STARR field studies. Fifteen State Lands oil and gas fields: eight in the Permian Basin, six on the Gulf Coast, and one in South Texas have been, or are being, evaluated.

Union Pacific Resources (now Anadarko), and Vista Resources (table 1). Project STARR has recommended 58 infill wells, 56 recompletions, and 4 step-out wells during its 5-year history.

Of the targeted opportunities, at least 41 infill wells and 29 recompletions have been drilled on State Lands on the basis of STARR recommendations. Twenty-eight recompletions have been undertaken in Ozona and Keystone East fields, and incremental oil and gas reserve growth is estimated at 8.8 billion cubic feet (Bcf) of gas and 2.44 million barrels (MMbbl) of oil. The total revenue generated from the reserves added in these two fields is projected to exceed \$48 million. In Umbrella Point and Red Fish Bay fields, total revenue to the State generated from one infill well and one recompletion is expected to exceed \$3 million.

HISTORICAL BACKGROUND

In 1839 the Republic of Texas began designating public lands to be used to benefit public schools, and the State of Texas now has more than 13 million acres set aside for revenue generation to assist public education (fig. 2). In the 158 years since that forward-looking decision was made, more than \$7 billion in revenue for public schools has been generated by agricultural and mineral leasing of these lands, with most of the revenues being derived from royalties and rentals paid for by oil and gas leases. In 1999, annual oil and gas income to the Permanent School Fund grew to \$139.8 million (Texas General Land Office and Veterans Land Board, 1999).

A vast volume of oil and gas remains in State Lands fields. Remaining oil in place on State Lands is 3.7 billion barrels (Bbbl) (fig. 3a), and remaining gas in place is 10 trillion cubic feet (Tcf) (fig. 3b). The hydrocarbons that remain are trapped in geologically complex reservoirs that require advanced technologies for successful, cost-effective recovery. The problem for the State and for public education is that these oil and gas resources must be produced for their value to be realized. With support from the State of Texas, Project STARR and Texas operators are responding to this charge.

Table 1. Project STARR fields and operators.

<u>STARR Fields</u>	<u>Operator</u>	<u>Project Period</u>
Keystone East field	Bass Enterprises Hallwood Energy Pioneer Natural Resources Vista Resources	1995–1999
Geraldine Ford and Ford West fields: (primary funding by U.S. Department of Energy)	Conoco, Incorporated	1995–1997
Lockridge, Waha, and Waha West fields: (primary funding by U.S. Department of Energy and Gas Research Institute)	Shell Oil Mobil Oil (now ExxonMobil)	1996–1998
Bar Mar field	Hanson Corporation	1997–1998
Ozona field	Union Pacific Resources (now Anadarko) Cross Timbers Oil Co.	1996–1998 1998–1999
Duval County Ranch fields	Killam Oil	1998–1999
Umbrella Point field	Panaco, Incorporated	1995–1999
Red Fish Bay field	Pi Energy	1996–1997
Corpus Christi East field	Sabco Oil and Gas Royal Exploration	1998–2000
Corpus Christi NW field	Sabco Oil and Gas Royal Exploration	1998–2000
Encinal Channel field	Sabco Oil and Gas Royal Exploration	1999–2000
Mustang Island 889 field	Sabco Oil and Gas	2000–2001

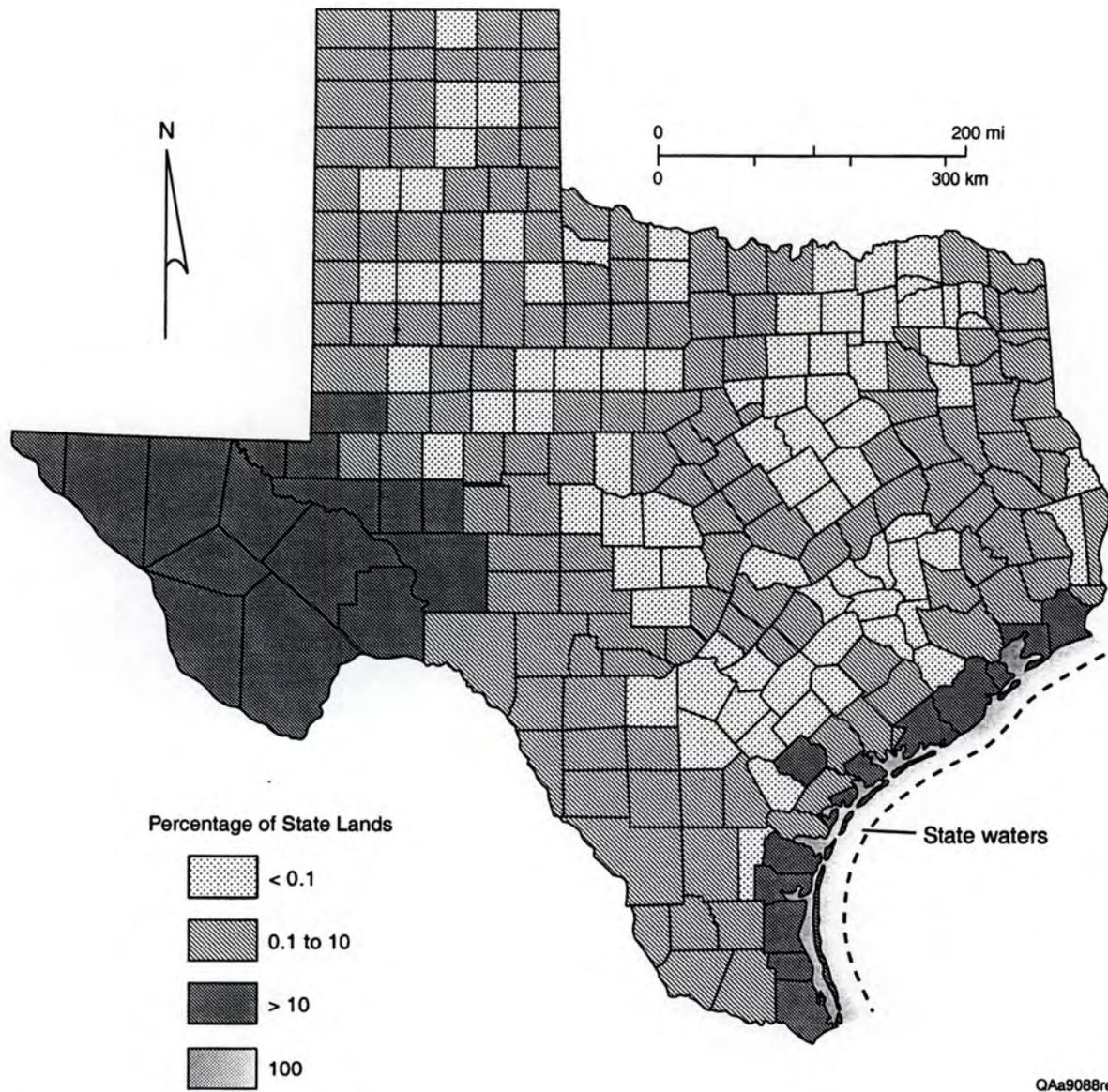
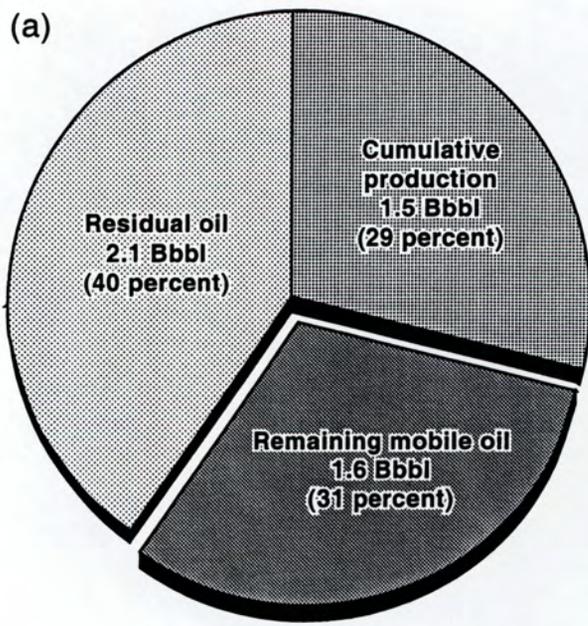
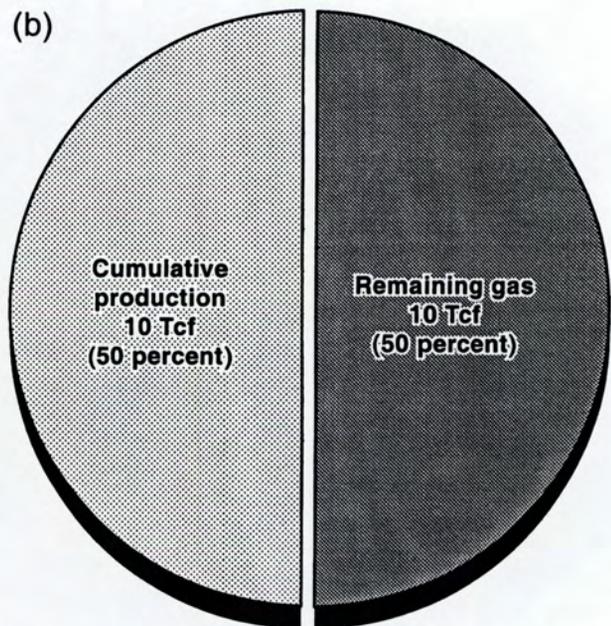


Figure 2. Location of Texas State Lands in State waters and on a percentage basis in each onshore county. The majority of onshore State Lands leases occur in the Permian Basin, West Texas, and along the Gulf Coast.



Original oil in place
5.2 billion barrels (Bbbl)



Original gas in place
20 trillion cubic feet (Tcf)

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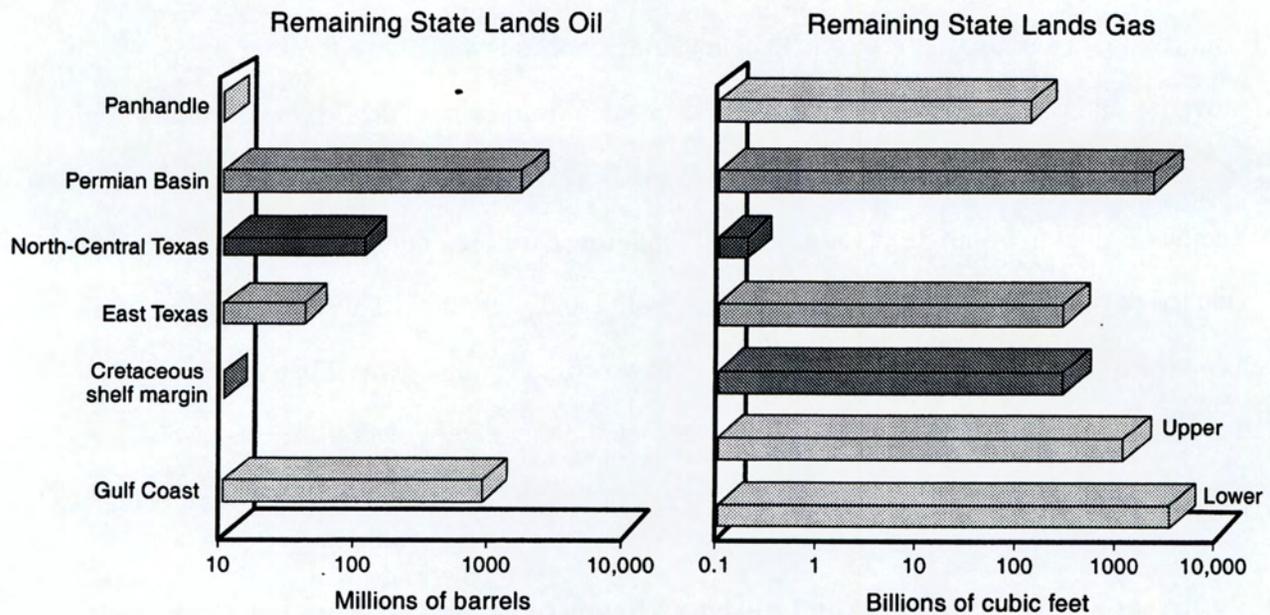
Figure 3. Texas State Lands volumetrics. (a) Despite a precipitous decline in revenues from State Lands oil production, only slightly more than one-quarter of the original oil in place has been produced. Remaining mobile oil is as large a recovery target as all the oil historically produced from State Lands fields. (b) These estimates of gas volume are conservative because they are based on relatively large gas fields that have produced more than 10 Tcf. Cumulative production is only half of the original gas in place.

STARR METHODOLOGIES

The philosophy of Project STARR is to work with field operators to deploy advanced recovery strategies on a field-by-field basis to ensure maximal recovery efficiency. The most volumetrically significant State Lands oil and gas resources are in the Gulf Coast and the Permian Basin (fig. 4). STARR's approach is to concentrate on these two mature resource areas, where innovative and cost-effective strategies can best be deployed to stem the decline of production. Fifteen State Lands fields, comprising eight West Texas fields (fig. 5), six Gulf Coast fields (fig. 6), and one field in South Texas (fig. 7), have undergone, or are undergoing, characterization and extended development with the cooperation of State Lands operators. This maximization of oil and gas recovery from State Lands fields consists of two critical components: (1) reservoir characterization and advanced resource recovery technology deployment in key reservoirs and (2) transfer of concepts and approaches to recovery optimization to State Lands fields and operators.

Reservoir Characterization and Advanced Resource Recovery Technology Deployment

The advanced hydrocarbon recovery program integrated into Project STARR is based on application of advanced reservoir characterization techniques that define the residency of unrecovered oil and gas in selected State Lands reservoirs. Project STARR staff work with operators to deploy advanced reservoir exploitation plans that are based on a thorough understanding of the internal architecture of the reservoir and the effects that depositional systems have on oil and gas distributions. Key to this effort is a scientific-based identification of oil and gas reservoirs that have significant incremental recovery opportunities. To implement these opportunities, Project STARR then has to identify and recruit field operators who are ready to address and redesign, as appropriate, development efforts currently in place on properties that overlie these reservoirs. Detailed geologic and engineering characterization has created quantitative descriptions of several State Lands reservoirs and identified untapped and bypassed compartments



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Figure 4. State Lands oil and gas volumes. The Gulf Coast and Permian Basin regions have the most volumetrically significant oil and gas targets.

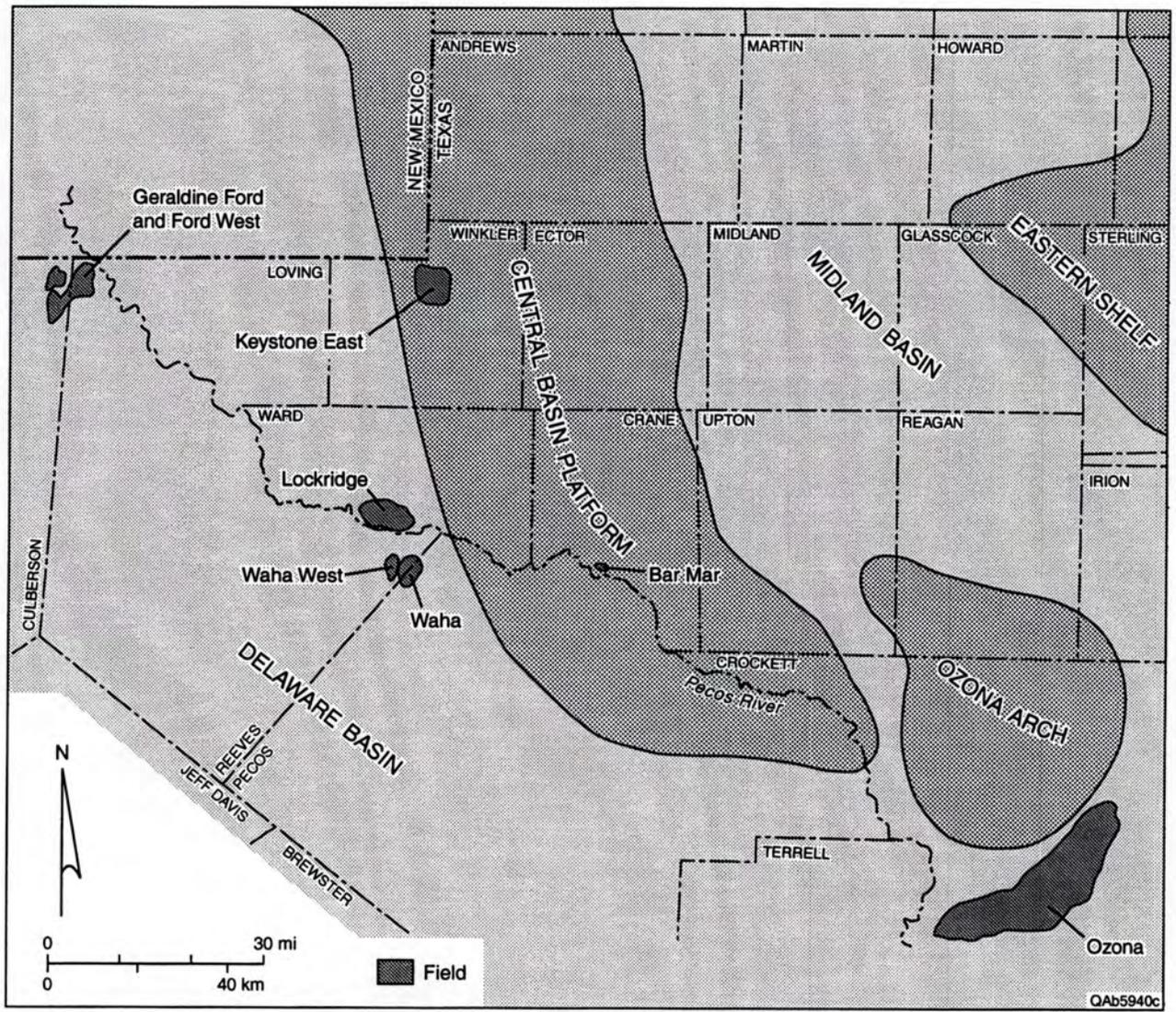


Figure 5. Location of STARR fields in the Permian Basin of West Texas.

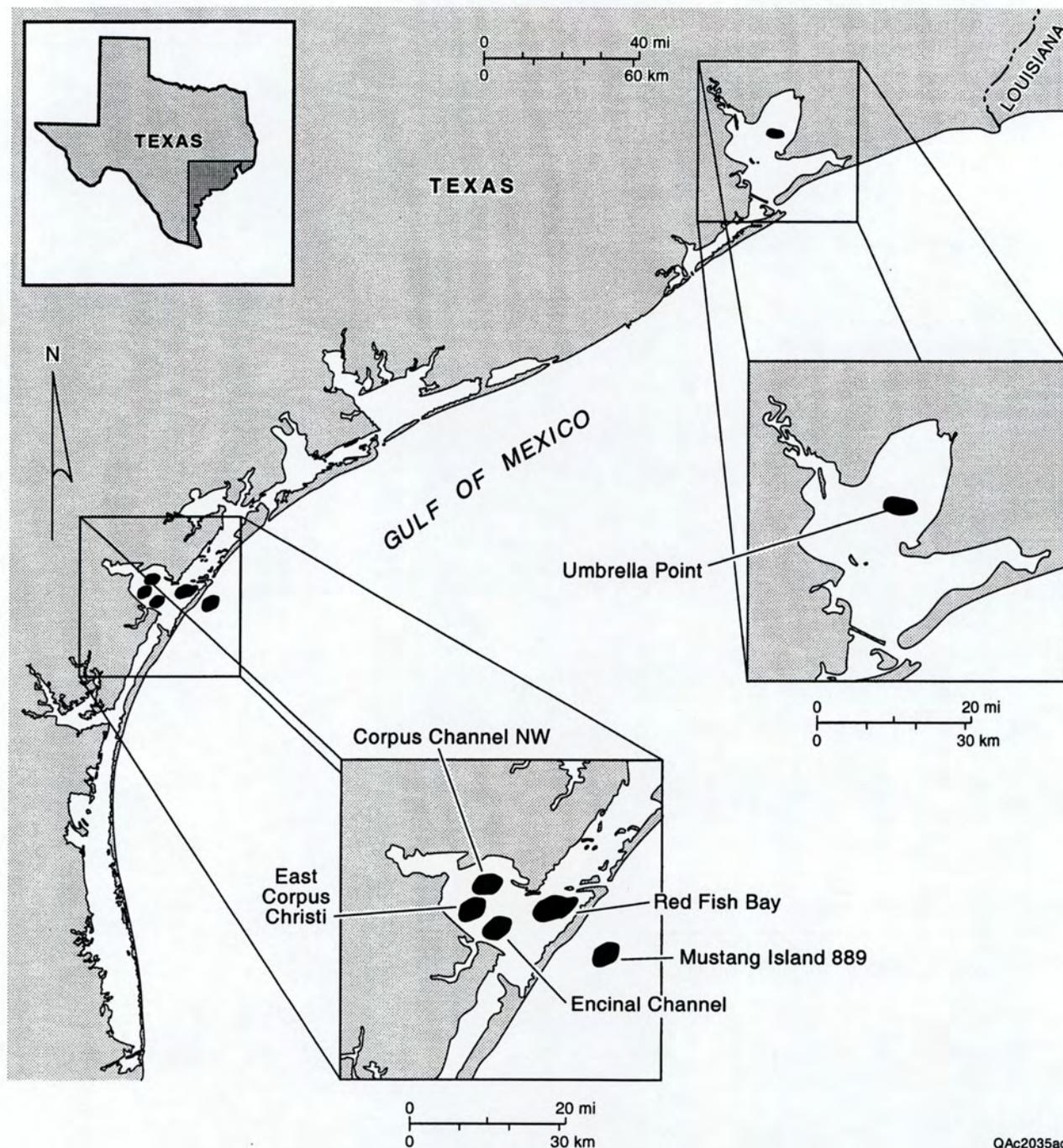


Figure 6. Location of STARR fields along the Texas Gulf Coast.

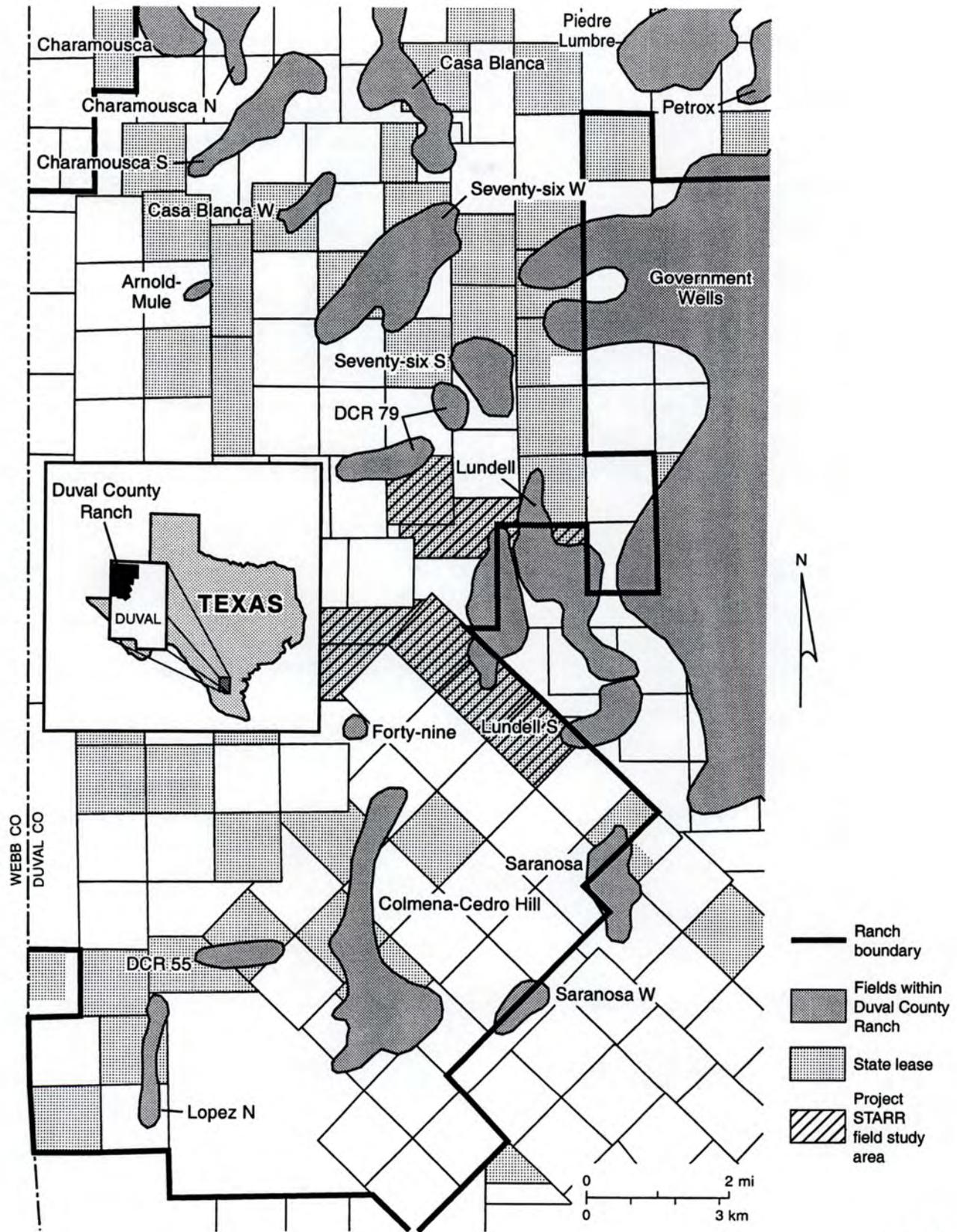


Figure 7. Location of STARR field study in South Texas

of remaining oil and gas. These STARR opportunities include reservoir characterization of the Geraldine Ford, Ford West, Lockridge, Waha, Waha West, Ozona, Keystone East, Umbrella Point, Bar Mar, Red Fish Bay, Duval County Ranch, Corpus Christi East, Corpus Channel NW, and Encinal Channel fields. A study over Mustang Island, Block 889 field, in Texas State waters is being initiated at the time of this report. The optimized recovery strategies recommended by the Bureau in these field studies include step-out wells, well deepening, recompletions, targeted infill drilling, injection profile modification, waterflood optimization, and hydrofracing.

Transfer of STARR Technology to Texas State Lands Operators

The success of the advanced recovery initiative, as measured in incremental barrels of oil in the tank and additional cubic feet of gas in the pipeline, is vitally important, but equally important is the transfer of successful approaches to improved oil recovery to operators of State Lands reservoirs. Because technology translation and extension facilitate the leveraging of improved efficiencies to State Lands fields, Project STARR has developed a multi-phase, multi-component approach to technology transfer that includes recovery technology extension activities, workshops, presentations, publications, and digital data sets (CD-ROM's).

In collaboration with the General Land Office and the Railroad Commission of Texas, Bureau project personnel have provided assistance and advice to numerous operators on optimizing development strategies, appropriate well-log suites, styles of reservoir heterogeneity and their effects on oil and gas recovery, and approaches to problem solution. State Lands operators involved in STARR initiatives include Bass Enterprises, Conoco, Hallwood Energy, Hanson Corporation, Killam Oil Company, Mobil (now ExxonMobil), Panaco, Pi Energy, Pioneer Natural Resources, Royal, Sabco, Shell, Union Pacific Resources (now Anadarko), and Vista Resources.

Through the transfer of technology developed by Project STARR to Texas operators, it is envisaged that many of the remaining State Lands oil and gas reserves will be explored and developed in the ensuing decades to sustain the Texas Permanent School Fund. As a result of this State funding, several awards have been received by Project STARR, and numerous publications

have been provided to the public. Individual awards, publications, workshops, and presentations are listed in the appendices.

PROJECT STARR'S RETURN ON STATE INVESTMENT

Production data from the Texas Railroad Commission show that STARR-generated wells have provided the following royalty revenue for the Permanent School Fund during the past 2 years (table 2). The revenue numbers in the last column of this table are calculated using \$2/Mcf for gas, \$16/bbl for oil and condensate, and 1/8 royalty to the Permanent School Fund.

Table 2. Royalty revenue into the Permanent School Fund (June 1998 to May 2000).

Field	Gas (Bcf)	Condensate (bbl)	Oil (bbl)	Revenue
Umbrella Point	7.9	75,000	—	\$2,125,000
Ozona	0.94	—	—	\$235,000
Bar Mar	0.002	—	11,000	\$45,000
				<u>\$2,405,000</u>

Comparing the total revenue with the \$895,000 of salary funding received from the State for August 1998 through August 2000, project STARR is revenue positive by a factor of 2.7 for the current 2-year reporting period.

The rate of decline in oil and gas production on Texas State Lands is symptomatic of the hydrocarbon production decline in the entire state over the past decades. In 1994, projected decline rates indicated that Texas oil and gas revenues could decrease to dramatically low levels within the next decade unless advanced reservoir characterization and technology transfer were undertaken. Current projections indicate that Project STARR is generating significant revenue for the Permanent School Fund. Within the fields currently evaluated, 58 infill wells, 56 recompletions, and 4 step-out wells, for a total of 118 reserve growth opportunities, have been recommended

(table 3). In Ozona, Keystone East, Umbrella Point, and Red Fish Bay fields alone, these targets could add 23.9 Bcf of gas and more than 2.6 MMbbl of oil to the reserves (table 4). The total revenue generated in the State of Texas from these reserves should be \$88.9 million. The bulk of this revenue (\$49 million) will come from three fields—Ozona and Keystone East in West Texas (fig. 5) and Umbrella Point in Galveston Bay (fig. 6). Tax revenue to the State General Fund from incremental oil and gas reserves is projected to exceed \$3 million during the 2-year span of current STARR funding.

With sustained oil and gas development funding from the State of Texas, Project STARR has an ultimate goal of capturing an incremental 2 percent of the remaining mobile oil resource of 1.6 Bbbl of oil on State Lands. Achieving this goal would provide a return to the State of \$84.6 million (assuming a price of \$16/bbl). The State General Fund would receive \$20.6 million in tax revenues, and the Permanent School Fund, \$64 million in royalty revenues. Similarly, a capture of 2 percent of the 10 Tcf of remaining gas would generate \$76.3 million for the State (assuming a price of \$2/Mcf). The State General Fund would receive \$26.3 million, and the Permanent School Fund, \$50 million in gas revenues. By achieving these modest levels of incremental recovery, the State Lands Oil and Gas Advanced Resource Recovery Initiative could generate \$160.9 million in taxes and royalties to the State, resulting in a significant contribution to the Permanent School Fund and direct benefit to all the citizens of Texas. Sustained funding for Project STARR will permit reservoir characterization analysis of several major oil and gas fields on State Lands per year and act as a catalyst that will bring advanced exploration and development technologies back onto State Lands and increase revenue flow to the Permanent School Fund.

Table 3. STARR infill, recompletion, and step-out recommendations.

Fields	Infill Wells	Recompletions	Step out
Ozona	23	0	0
Keystone	26	28	0
Umbrella Point	4	4	0
Red Fish Bay	0	21	0
Lundell	0	1	0
Bar Mar	3	2	2
Waha/Lockridge	0	0	2
Corpus Christi East	2	0	0
Corpus Christi NW	0	0	0
Encinal Channel	<u>0</u>	<u>0</u>	<u>0</u>
TOTALS:	58	56	4

Table 4. STARR recommendations and total reserves added. ^{potential for}

Fields	Infill Wells	Recompletions	Reserves	
			Oil (bbl)	Gas (Bcf)
Ozona	16	0	560,000	8.0
Keystone	22	28	1,880,000	0.8
Umbrella Point	1	0	90,000	15.0
Red Fish Bay	0	1	71,883	0.1
Corpus Christi East	<u>2</u>	<u>0</u>	<u>—</u>	<u>6.0</u>
TOTALS:	41	29	2,601,883	29.9

RESERVES ADDED
2.6 MILLION BARRELS OF OIL
30 BILLION CUBIC FEET OF GAS

RECOMMENDATION

Project STARR focuses on field-scale studies that are limited in their geographical extent. This concentrated focus on small, reservoir-size areas leads to immediate royalty revenue flow into the Permanent School Fund because specific Earth coordinates and specific reservoir depths can be identified where State Lands operators can take recommended actions to increase production.

An alternate philosophy that can benefit the State and the Permanent School Fund on a longer term basis would be to expand program STARR so that large, regional-scale studies can be done to identify new play trends across State Lands properties. These large-scale studies would be an ideal complement to the current, small-scale STARR projects and provide a multi-year focus and a long-term technology implementation that will better sustain the Permanent School Fund.

The Bureau of Economic Geology recommends that funding for project STARR be incremented to allow the program to do regional-scale studies. These large-scale studies may have a slower rate of revenue generation than do reservoir-scale projects, but they should create a larger magnitude of revenue flow for the State and sustain that revenue generation for a longer period of time than do reservoir-scale studies.

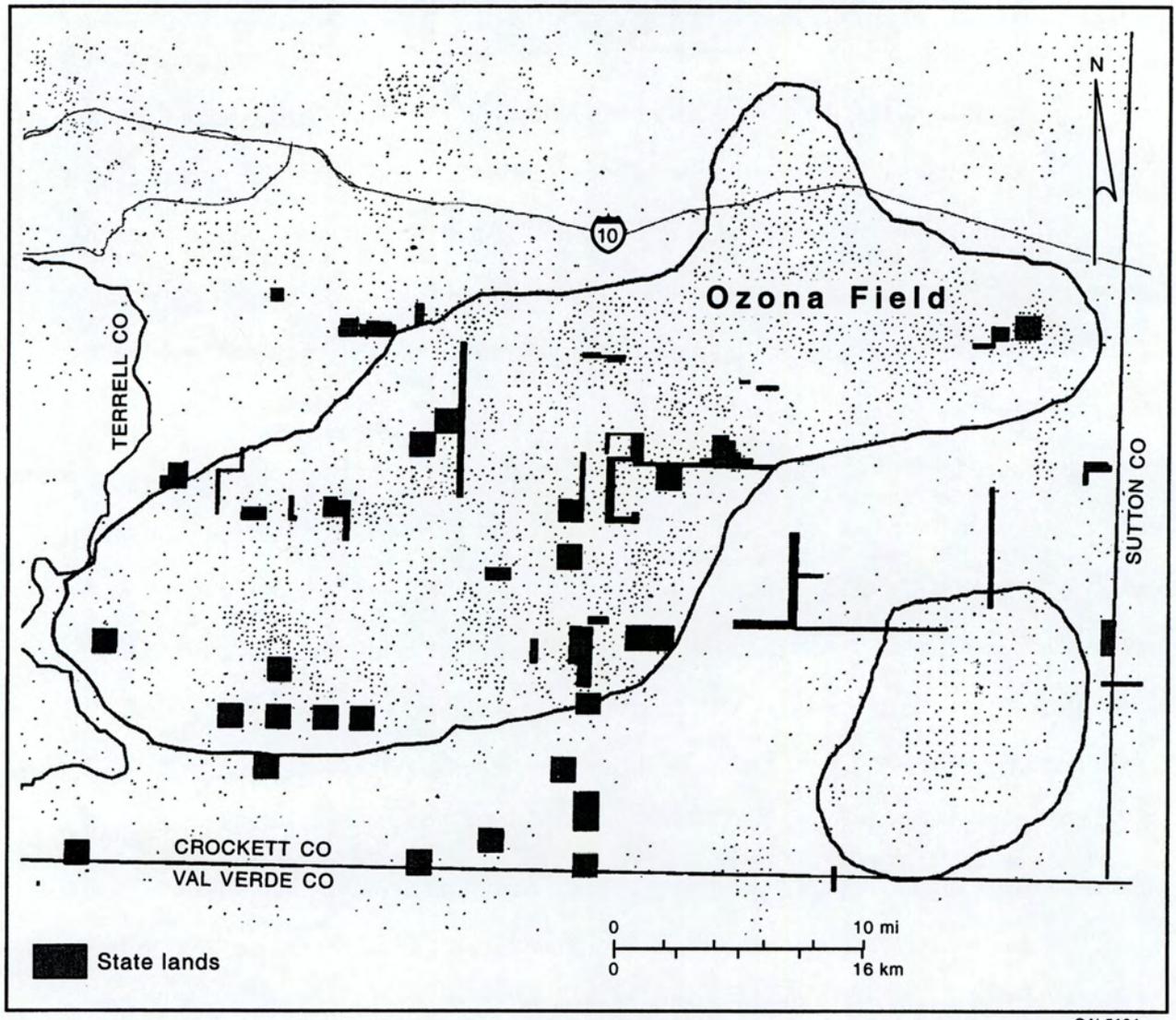
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Appendix A. Ozona Field

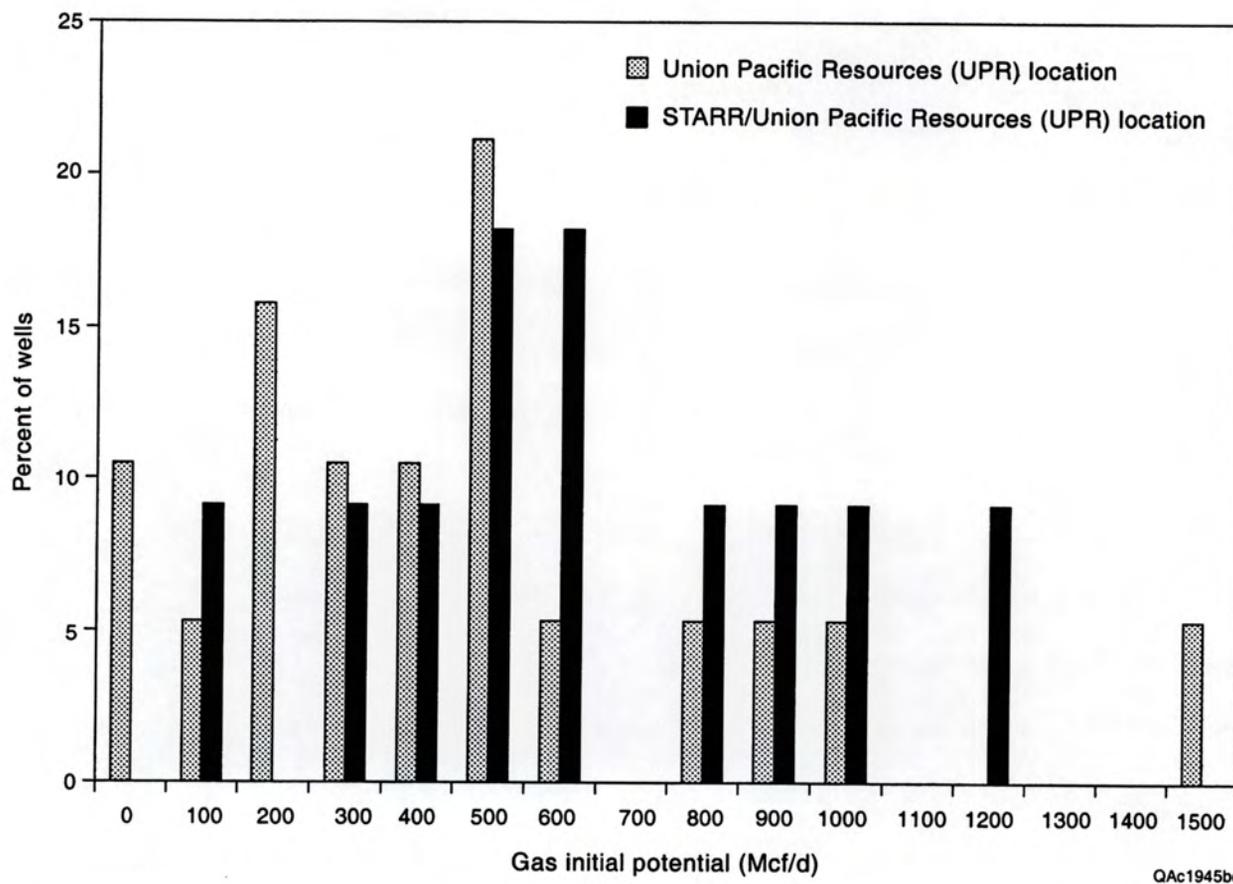
Ozona gas field in Crockett County has produced 1 Tcf of gas from more than 2,000 wells and includes approximately 24 mi² of State Lands. STARR did a geologic characterization of Ozona Canyon sandstone gas reservoirs on 18 mi² of State Lands in the field and on another 8 mi² of State Lands just outside the present field boundaries (fig. A1). This work assessed and ranked the production potential of most of the State Lands locations available for development. Union Pacific Resources Company (UPR) of Fort Worth (now Anadarko Oil and Gas) completed 16 wells on STARR-recommended State Lands locations. STARR is currently seeking additional industry partners who are active in this area to continue the drilling successes and operator relationships developed on these State Lands.

Advanced reservoir characterization will be a continuing effective tool for increasing oil and gas production on State Land leases in the Ozona field. Most Ozona sandstone reservoirs form narrow belts or ribbons resulting from their deposition in channels on ancient sea floors. Well locations can be selected by targeting the thickest parts of these sandstone trends, as has been demonstrated by wells based on STARR recommendations. Production results show that geologically targeted locations in Ozona field are above-average producers (fig. A2). As a result of the STARR initiative, projected recovery from the 16 project wells is estimated to be 8 Bcf of gas and 560 Mbbl of oil and natural-gas liquids (table 4). Assuming a price of \$16/bbl for oil and \$2/Mcf for gas, royalty revenue to the Texas Permanent School Fund from June 1998 through April 2000 has been over \$0.2 million (table 2).



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Figure A1. Location of Ozona gas field and State Lands, Crockett County, Texas.



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Figure A2. Histogram showing distribution of potential productivity of Ozona gas wells. Initial potential tests (IP's) are a general measure of ultimate recovery. STARR-recommended locations on State Lands have an average IP of 607 Mcf/d of gas versus an average of 366 Mcf/d of gas for a randomly selected group of recent Union Pacific Resources (now Anadarko) Ozona completions.

Appendix B. Keystone East Field

Keystone East field is in Winkler County on the northwest side of the Central Basin Platform (figs. 1 and 5). Project STARR estimates the original oil in place in this field to be approximately 106 MMbbl. Cumulative production is about 19 MMbbl, or only 18 percent of the original oil in place. Recoverable reserves are estimated to be 19 MMbbl for the total field. Project STARR work added almost 2 MMbbl of reserves (table 4).

Project STARR provided technical support to four Texas State Lands operators in Keystone East field: Bass Enterprises, Hallwood Energy, Pioneer Natural Resources, and Vista Resources. Five wells were drilled in 1997, bringing the total new wells that STARR has recommended to date to 22, along with 28 recompletions (fig. B1). This development activity has resulted in a production increase of 140 percent, corresponding to a production rate of 774 bbl/d (fig. B2). The incremental production to date resulting from STARR technology support includes 480,698 bbl of oil and 835 Mcf of gas. At average wellhead prices of \$16/bbl for oil and \$2/Mcf for gas, the State's one-eighth royalty resulted in \$1,170,146 of incremental revenue through December 1997, which was reported in the previous STARR report (Tyler and others, 1998). No revenue from Keystone East field is included in this current STARR report.

STARR work has focused on modeling, implementation of a secondary recovery program, and evaluation of perforation locations and pay connectivity. It is projected that secondary recovery can increase the State Lands reserve base by two-thirds in this field, which will result in a projected royalty revenue to the Texas Permanent School Fund of \$3.9 million over the lifetimes of such projects.

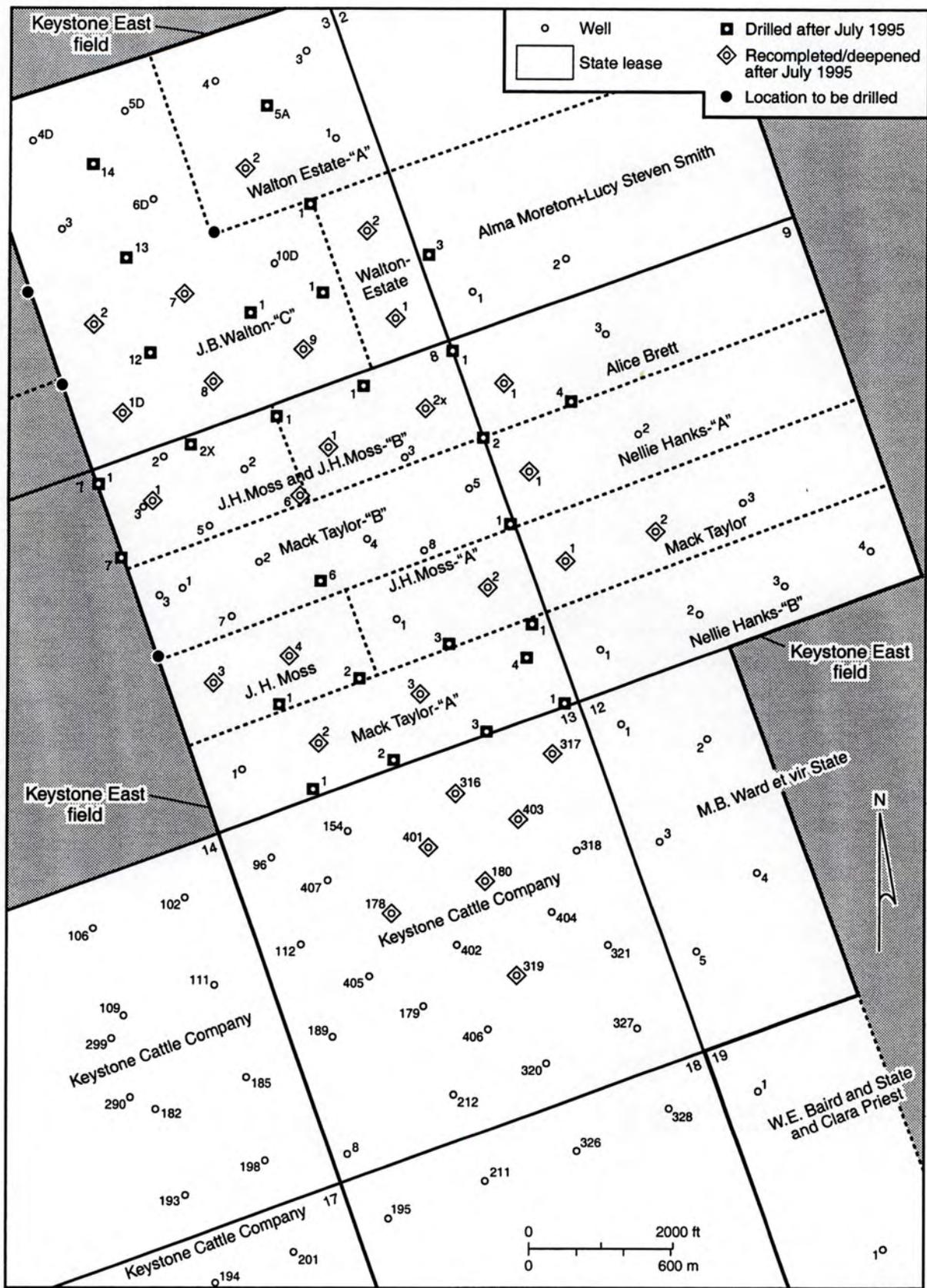


Figure B1. Location of Keystone East field in Winkler County, Texas. STARR development forecast has resulted in 22 new wells and 28 recompletions.

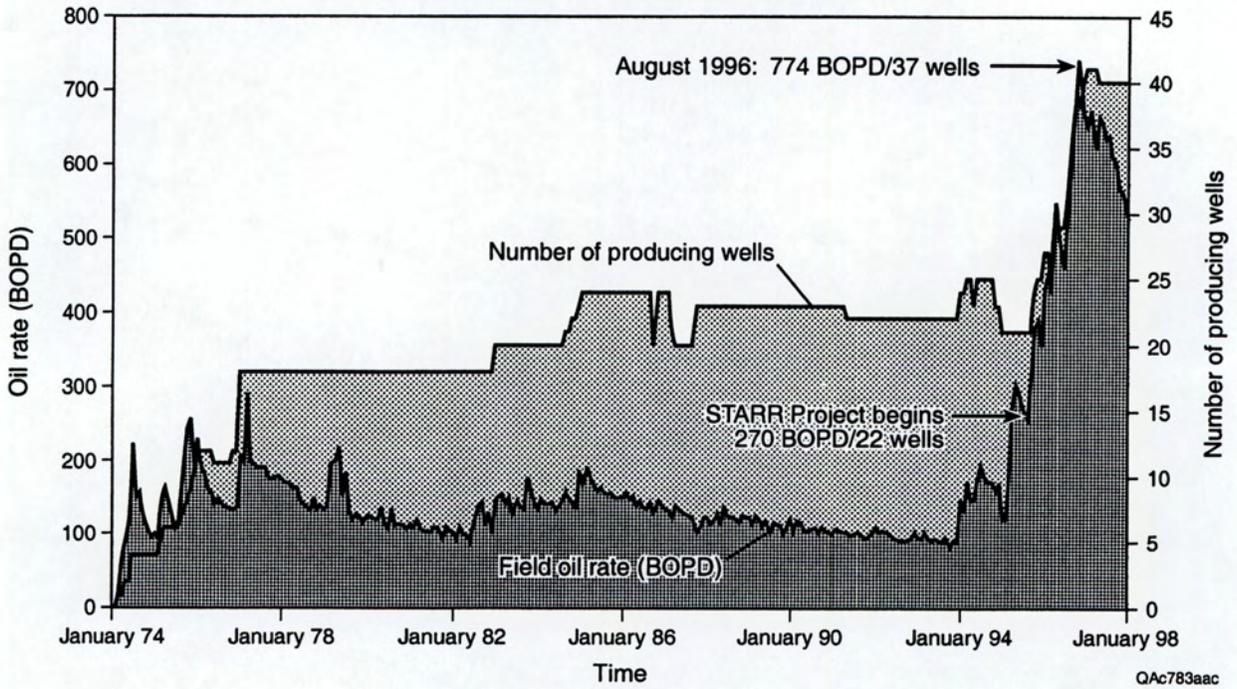


Figure B2. Production history of Keystone East field illustrating a 190-percent peak production increase since the beginning of the STARR project.

Appendix C. Umbrella Point Field

Project STARR worked with Panaco, Inc., of Houston, Texas, to improve oil and gas production from Umbrella Point field in Galveston Bay, Chambers County (fig. 6). Previously, the operator of these State Lands leases was Goldking Oil and Gas. Umbrella Point field produces oil and gas from Gulf Coast Frio barrier island/strandplain sandstones. Cumulative production from the middle Frio at Umbrella Point field through mid-1997 was 17 MMbbl of oil and 103 Bcf of gas from 36 wells developed in 15 zones at depths from 8,000 to 10,000 ft. In late 1997, when STARR began work at Umbrella Point, daily production was 189 bbl of oil and 2.8 MMcf of gas from 11 completions in 10 wells.

Remaining hydrocarbons in place are estimated to be 32 MMbbl of mobile oil and 173 Bcf of gas. Project STARR recommended four infill wells and four recompletions (fig. C1). Twenty-three prospect locations were also recommended to Panaco on the basis of their prospect criteria and Bureau mapping and 3-D seismic interpretation. Using STARR's interpretation of 3-D seismic data, Panaco completed an Umbrella Point gas well in the lower Frio Formation in January 1998. On initial test, the well flowed 11.5 MMcf/d of gas with 220 bbl/d of liquids. Gas production from this well has increased total field production significantly (fig. C2). This well is a significant contribution to the Permanent School Fund, having produced 7.9 Bcf of gas and 75,000 barrels of condensate from June 1998 through April 2000. At \$2/Mcf for gas and \$16/bbl for condensate, royalty revenue to the Permanent School Fund totals \$2.125 million (table 2). Panaco is continuing development by evaluating new recompletions and infill targets in the Umbrella Point field.

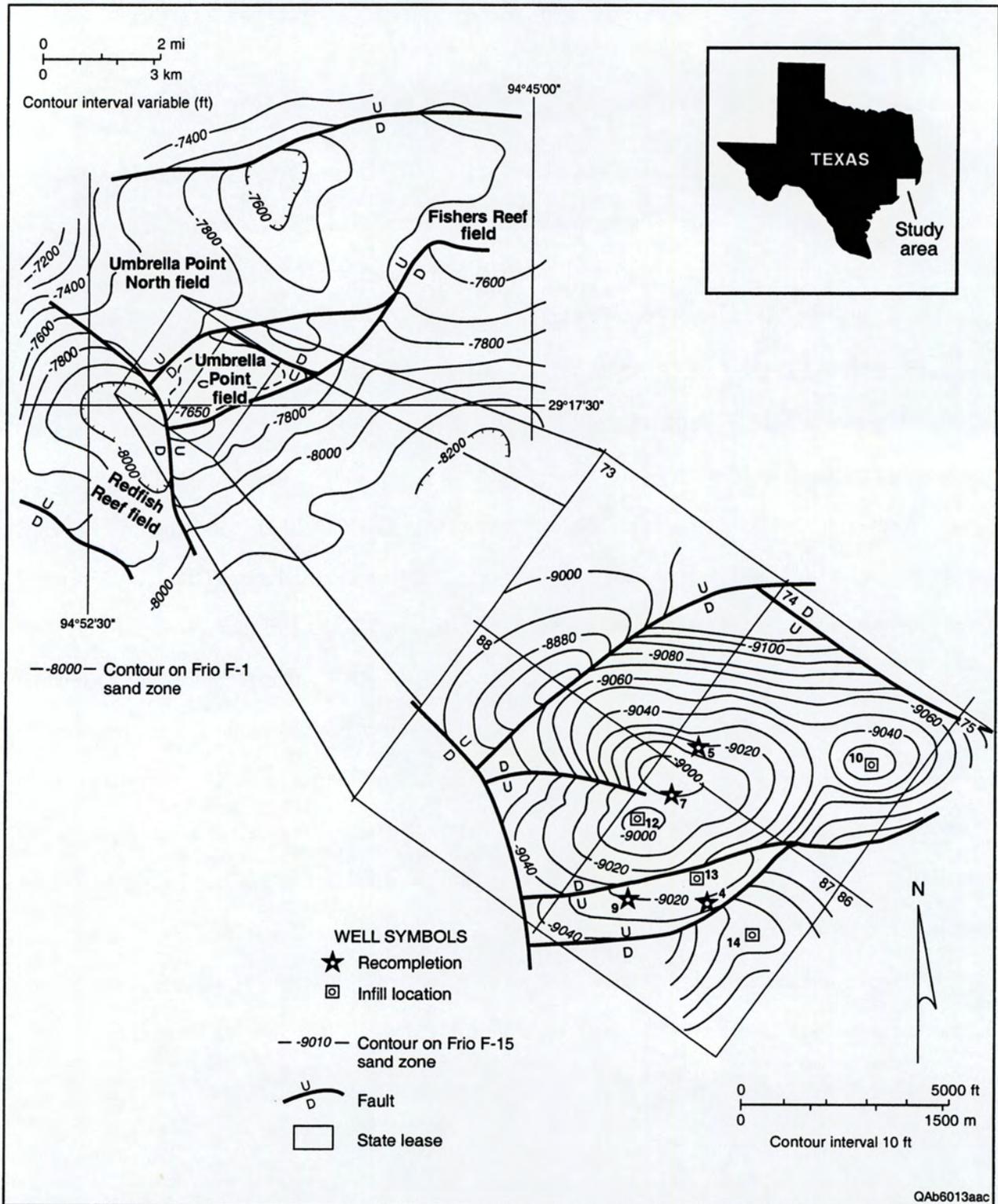


Figure C1. Location and structural setting of the Umbrella Point field, Galveston Bay, Chambers County, Texas. Project STARR recommended four infill wells and four recompletions.

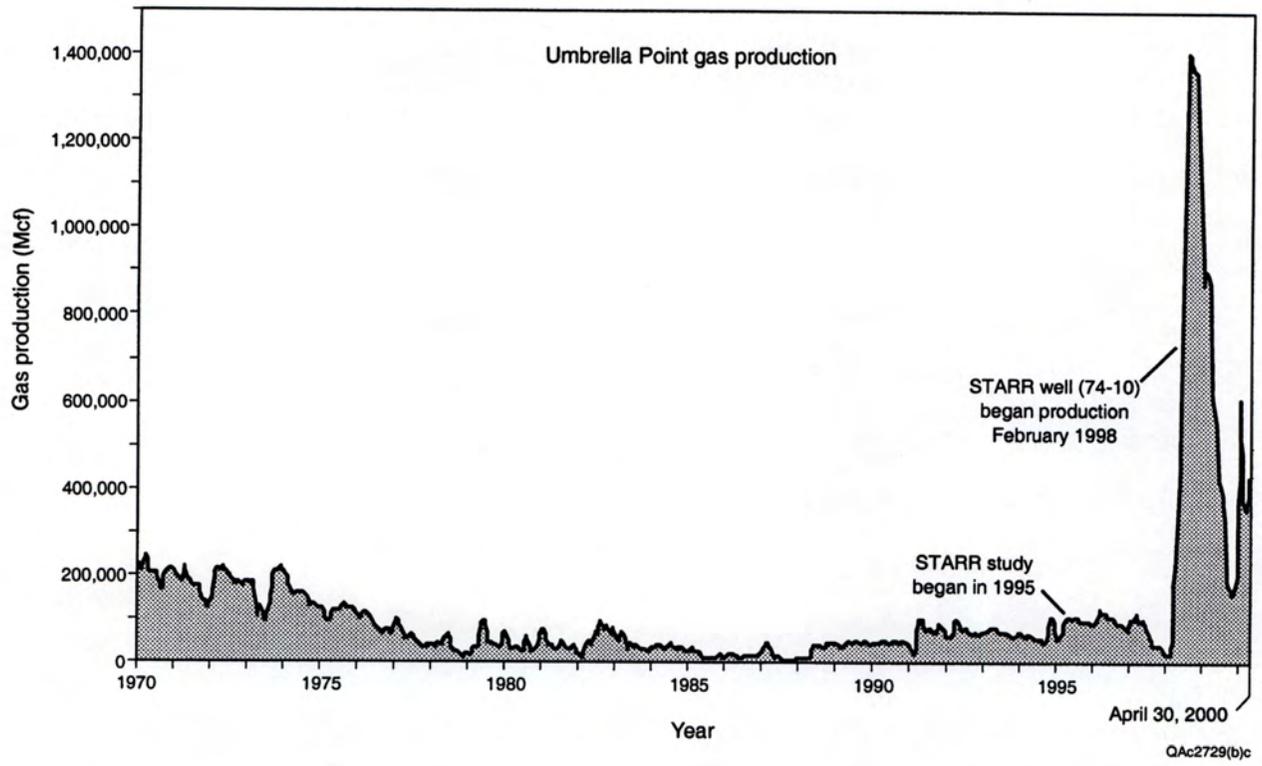


Figure C2. Umbrella Point field monthly gas production from January 1970 through April 2000.

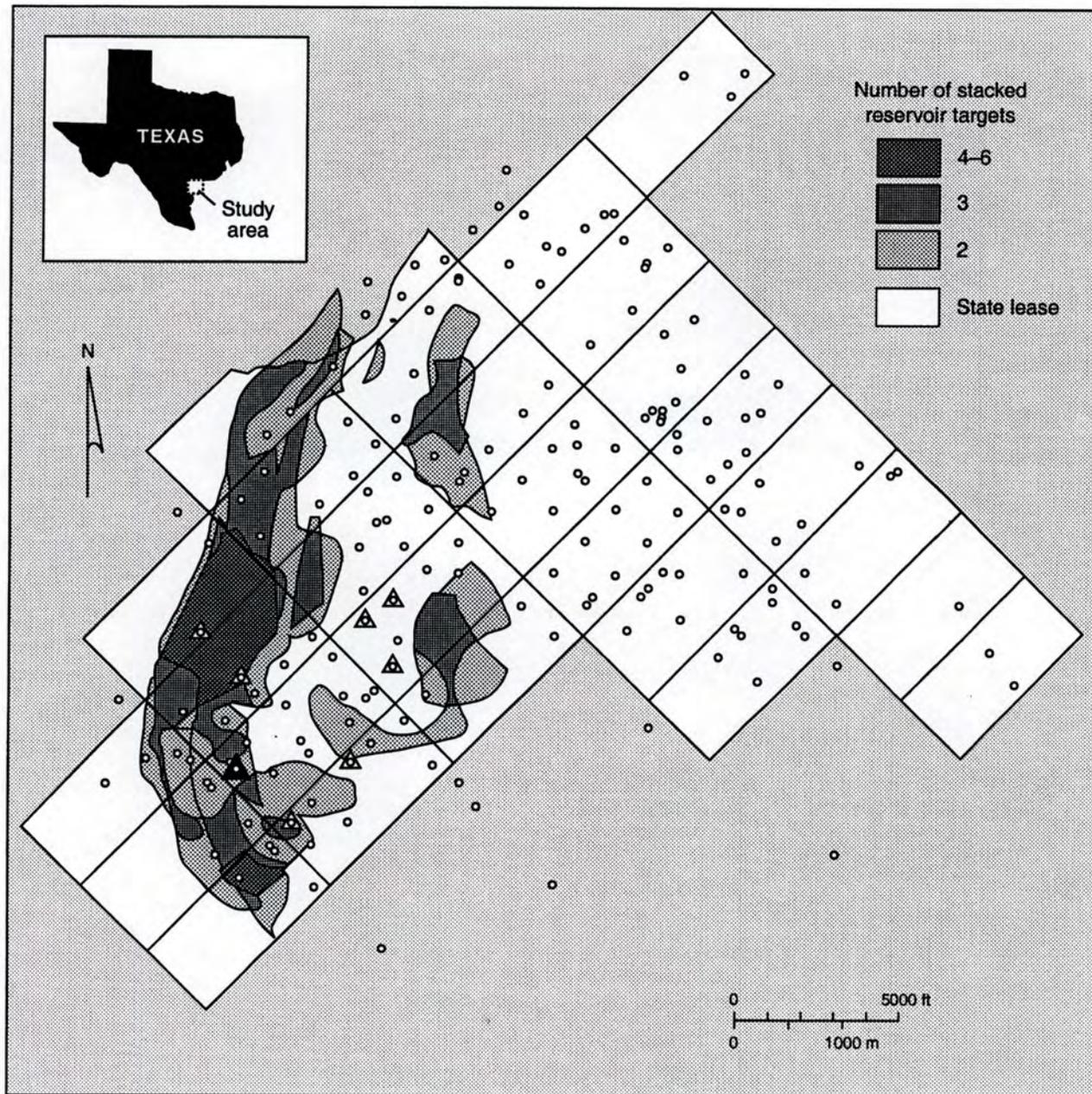
Appendix D. Red Fish Bay Field

Red Fish Bay field, Nueces County, Texas, lies in the downdip Frio Barrier Island/Strandplain-to-Shoreface/Shelf play 5 mi southeast of Aransas Pass in Corpus Christi and Red Fish Bays (fig. 6). Since field discovery in 1950, 19 MMbbl of hydrocarbon liquid and 103 Bcf of gas have been produced from 50 sandstone reservoirs in the middle to upper Frio Formation.

Nineteen upper Frio Formation reservoirs, at depths of 7,300 to 8,500 ft, account for approximately 80 percent of the field's total hydrocarbon production. These reservoirs were largely abandoned in the early 1970's by operators who considered upper Frio reservoirs to be depleted. Subsurface mapping by STARR staff has shown that extensive areas containing thick sandstone reservoirs within the oil and gas columns remain untapped.

Project STARR identified 21 prospective oil and gas recompletion opportunities in Red Fish Bay field. There are substantial underdeveloped reservoir regions that have few wells or plugged and abandoned wells that were completed in other reservoirs. Exploitation of these areas will require drilling of infill wells. Because of the multiple stacked reservoirs in Red Fish Bay field, many infill-drilling targets overlap, and regions having as many as four to six stacked reservoirs have been delineated (fig. D1).

Preliminary estimates of remaining hydrocarbon potential indicate that 60 MMbbl of mobile oil and 13 Bcf of gas remain in the reservoirs. Recommended recompletion and infill-drilling strategies should yield an additional estimated 7 MMbbl of oil and 5 Bcf of gas from Red Fish Bay field. In late 1997, Pi Energy performed a STARR-recommended recompletion that tested 200 bbl/d and was then choked back to 80 bbl/d. This recompletion represents a significant increase over the 30-bbl/d total field production that existed when the study began and increased the known reserves for the field (table 4). Projected royalty revenue to the Texas Permanent School Fund from this well is \$167,000. No royalty revenue from Red Fish Bay field is included in this report because a recent change of ownership has introduced some confusion into the production history.



- △ STARR recompletion opportunity
- ▲ STARR-recommended recompletion
- Well

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Figure D1. Proposed STARR infill-drilling opportunities for oil reservoirs in Red Fish Bay field, Nueces County, Texas. Optimal drilling sites contain as many as four to six stacked prospective targets.

Appendix E. Lundell and Forty-Nine Fields, Duval County Ranch

Project STARR worked with Killam Oil Co., Ltd., to seek exploration and infill-drilling opportunities in the Duval County Ranch area, Duval County, South Texas (fig. 7). About 5,000 acres of State Lands were included in the study area, with an additional 6,000 acres available for development on the periphery of the fields. Killam Oil leased several blocks of State Lands within the area and is actively drilling on State Lands leases.

The study area is located between Lundell and Forty-Nine oil and gas fields on the productive Jackson-Yegua trend. Total cumulative production from the two mature fields has reached 12 MMbbl of oil and 27 Bcf of gas. The targeted reservoirs for the extended recovery program are relatively shallow—between 1,500 and 2,400 ft. Detailed geological reservoir characterization has identified the distribution, thickness, quality, compartmentalization, and trapping mechanisms of the reservoirs. Exploration and improved recovery opportunities are being identified on the basis of the geological analysis.

To date, reservoir characterization has demonstrated the presence of untapped and/or bypassed oil and gas reservoirs in an area of approximately 2,000 acres. One infill-drilling location on State Lands was recommended to the operator (fig. E1). Access to a larger data base from the operator has improved geological reservoir characterization of the fields and the chances of finding additional reserves. The potential production of the new well could be comparable to that of Forty-Nine field, where drilled recommendations have increased oil several tens of barrels per day.

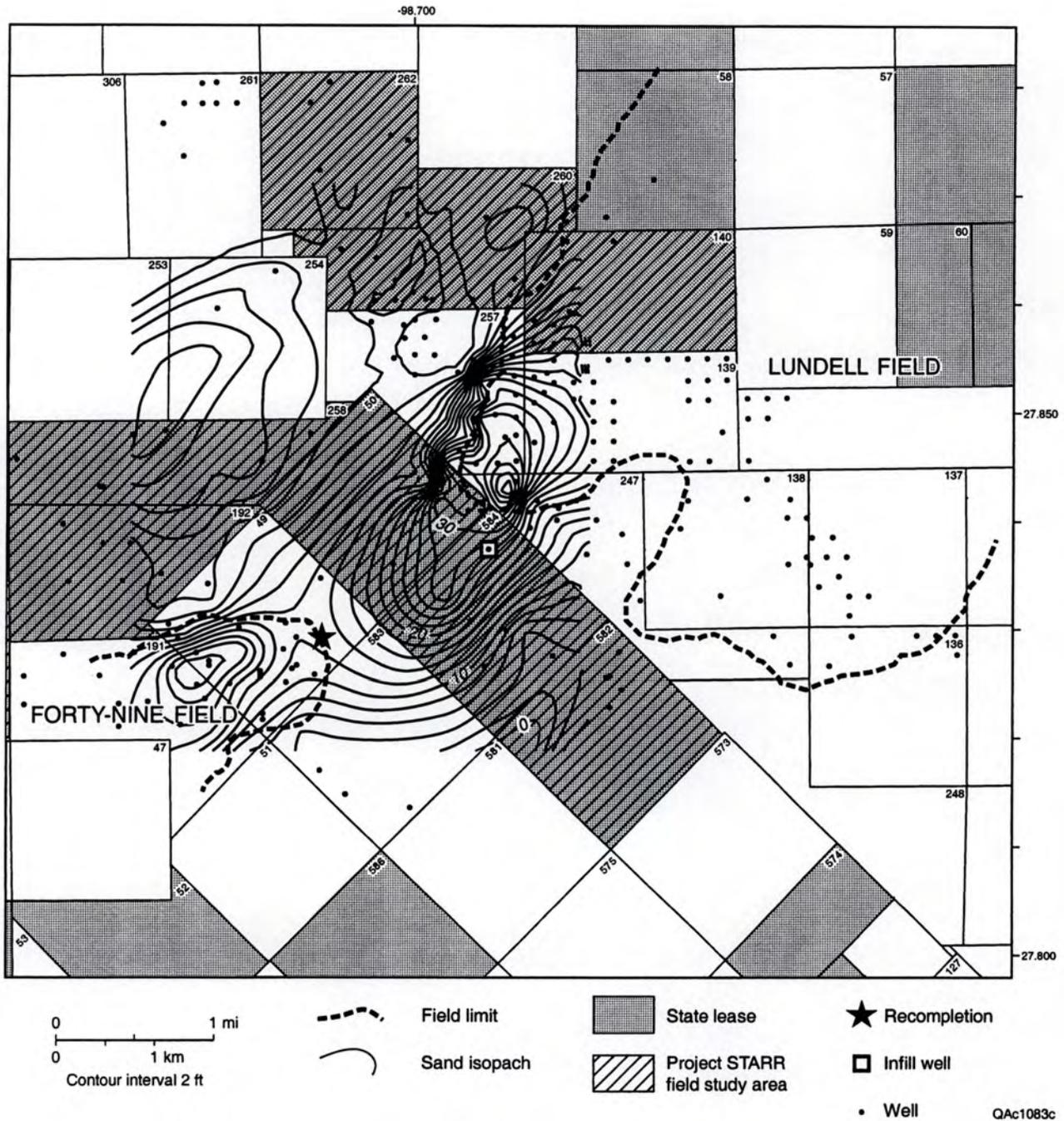
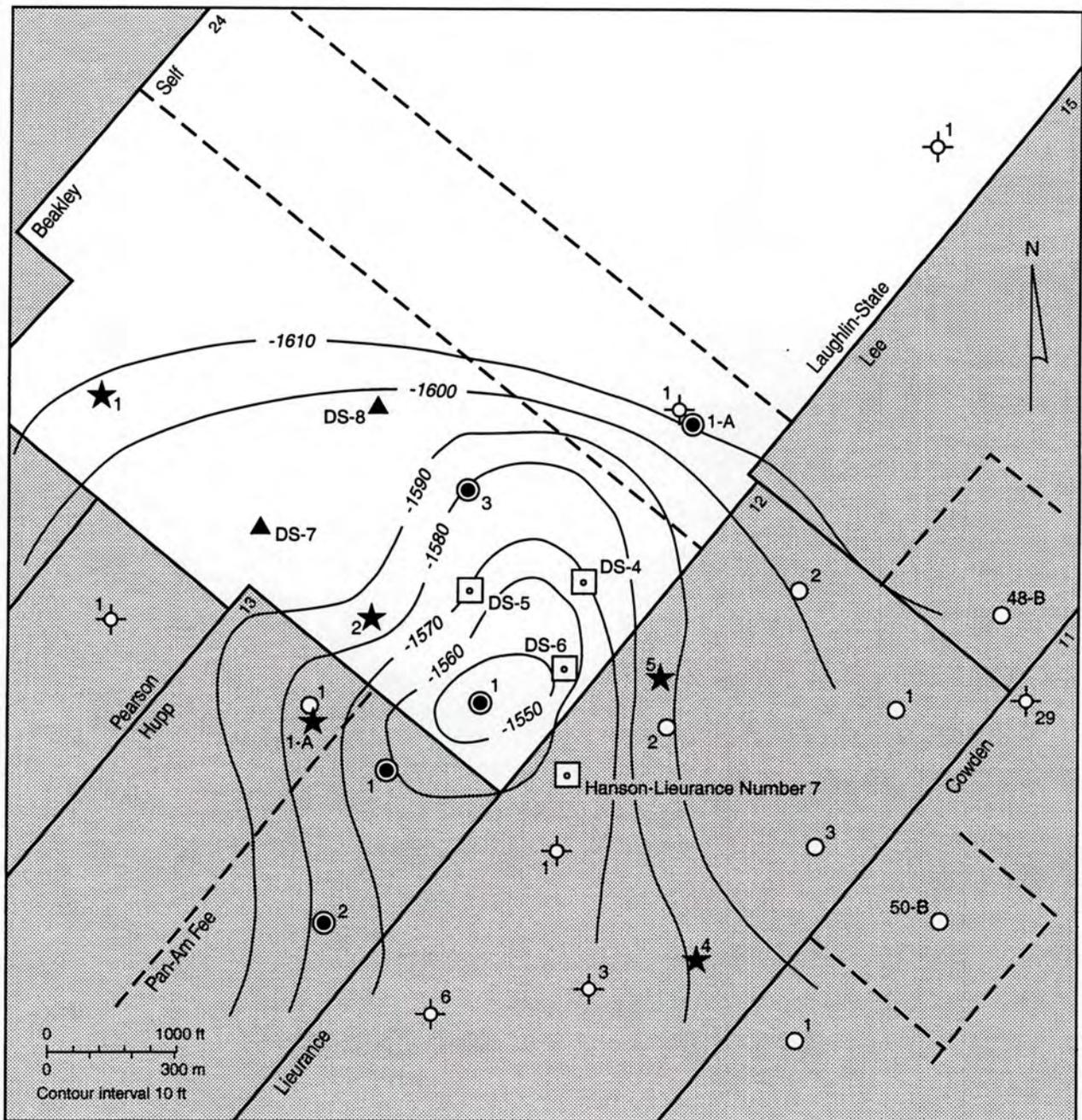


Figure E1. Location of Lundell and Forty-Nine fields, Duval County Ranch area, Duval County, South Texas. STARR investigation focused on the underexplored area between the two fields. Also shown are a sand-isopach map and location of STARR-recommended well actions resulting from preliminary geological reservoir characterization in this study.

Appendix F. Bar Mar Field

Bar Mar field is located in the southern Central Basin Platform (fig. 5) in Crane County, Texas, and is part of the West Texas Leonardian Restricted-Platform Carbonate play. STARR demonstrated to operators of this field that reserve additions will occur in Leonardian Restricted-Platform Carbonate play reservoirs when advanced resource optimization strategies are implemented.

Project STARR provided advanced technical and engineering support to Hanson Corporation for field development and recommended a development plan for Bar Mar leases that included three infill wells, two step-out wells, and two recompletions on State Lands leases (fig. F1). Infill wells and recompletions were targeted to increase primary recovery efficiency and to position wells for a secondary recovery project. Recommended step-out wells will test the boundaries of the reservoir to increase recovery efficiency. These STARR recommendations generated \$45,000 of royalty revenue for the Permanent School Fund from June 1998 through April 2000 (table 2).



- | | | | |
|---|-------------------|---|---------------------------|
| ▲ | Step-out location | ● | Lower Clear Fork producer |
| □ | Infill location | ⊗ | Plugged and abandoned |
| ○ | Well | □ | State lease |
| ★ | Recompletion | | |

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Figure F1. Location map of Bar Mar field, Crane County, Texas. STARR development plan includes three infill wells, two step-out wells, and two recompletions.

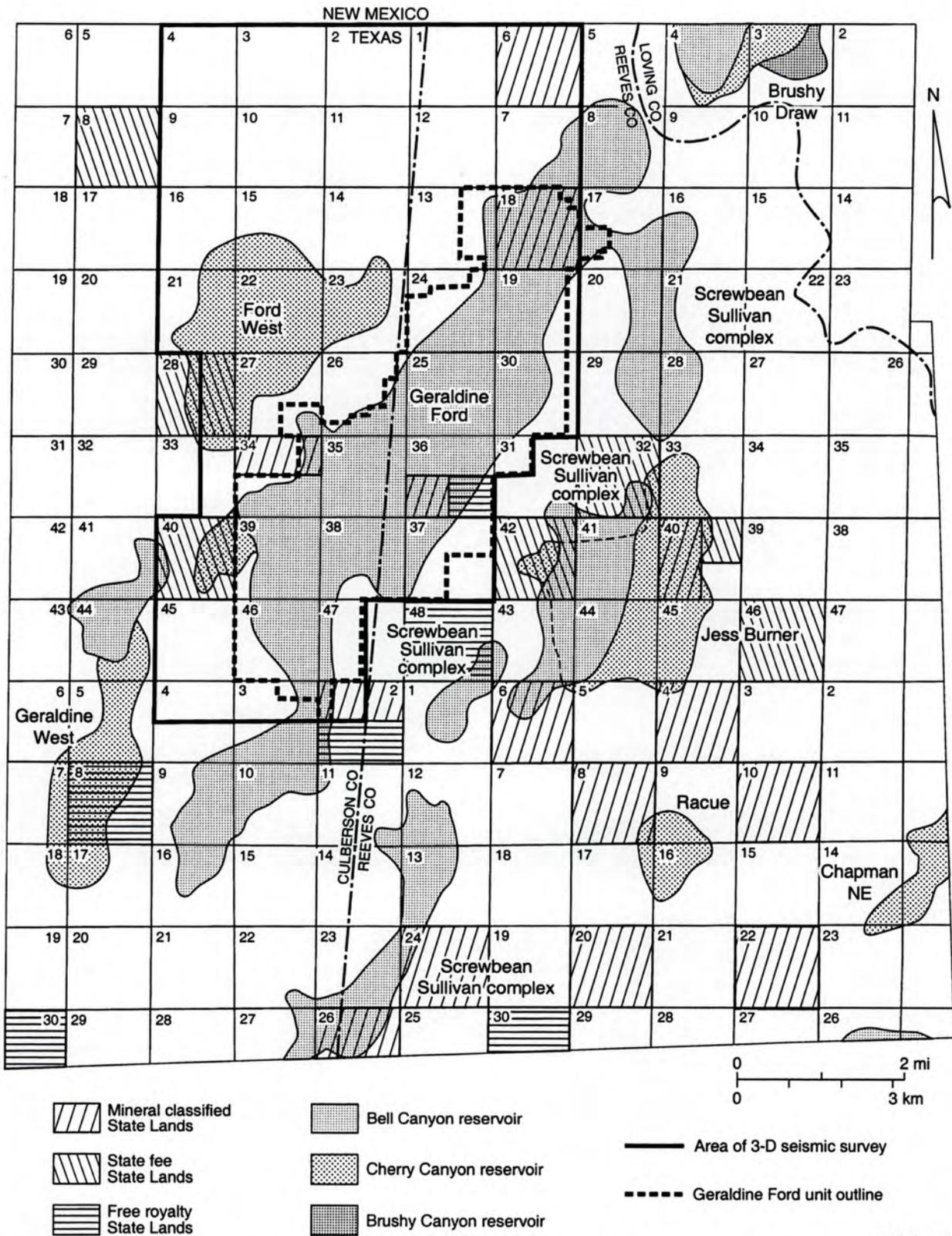
Appendix G. Geraldine Ford and Ford West Fields

Reservoir characterization of the Bell Canyon (Permian) Ramsey sandstone interval within the Ford Geraldine unit, Reeves and Culberson Counties (figs. 5 and G1), was done through joint funding from the U.S. Department of Energy, Conoco, Inc., the Texas Office of State-Federal Relations (through State Match Pool Funding), and STARR. The objective of this project was to demonstrate that detailed reservoir characterization of slope and basin clastic reservoirs in sandstones of the Delaware Mountain Group in the Delaware Basin of West Texas and New Mexico is a cost-effective way to recover original oil in place.

Phase 1 of the project, reservoir characterization, provided a detailed understanding of the architecture and heterogeneity within the Ford Geraldine unit. After reservoir characterization was completed, an area of approximately 1 mi² at the north end of the Ford Geraldine unit was chosen for reservoir simulation. Flow simulations were performed on a CO₂ flood to estimate the tertiary recovery potential. Results indicated that 10 to 30 percent (1 to 3 MMbbl of oil) of the remaining oil in place in the demonstration area could be produced by CO₂ injection.

Phase 2, a CO₂-injection demonstration, is proceeding in East Ford field with Orla Petco as the industry partner. The objective of Phase 2 is to test the effectiveness of CO₂ flooding to improve recovery in a mature Ramsey sandstone field. Orla Petco is a recognized leader in CO₂ flooding, and their expertise will benefit project and industry supporters and the Permanent School Fund through their role in technology transfer.

No royalty revenues from Geraldine Ford and Ford West fields are included in this report because a new operator (Primrose Operating Company) has purchased the properties and has not yet implemented any STARR recommendations.



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Figure G1. Outline of Geraldine Ford and Ford West fields, 3-D seismic survey, and location of State Lands in Culberson and Reeves Counties, Texas. The 3-D seismic survey, costing more than \$1 million, was developed over State Lands leases, and the knowledge and technology gained from interpreting these data will be applied to increase production in other State Lands reservoirs.

Appendix H. Waha-Lockridge Fields

With cofunding from the Gas Research Institute, the U.S. Department of Energy, and the State of Texas, Project STARR jointly participated in a multi-disciplinary reservoir characterization study of Ellenburger Group reservoirs in a 176-mi² area of West Texas in the southern Delaware Basin. The objective of the study was to investigate gas reserve growth in complex carbonate reservoirs. The advanced recovery area, which comprises Lockridge, Waha, and Waha West fields (fig. 5) and parts of Worsham-Bayer and Coyanosa fields, has produced 1.3 Tcf of natural gas since initial discovery of these fields in the 1960's.

Quantitative evaluation of wireline logs, structural mapping, and evaluation of pressure and production data indicate that the dominant control on Ellenburger gas production in this area is natural fractures produced by tectonic deformation. In particular, fractures associated with faults and with maximum flexure on positive structural features control the locus of highest Ellenburger reservoir quality and production. Matrix porosity does not vary significantly in Ellenburger reservoirs within these fields and does not appear to be a significant factor in reservoir quality. Recommended drilling locations were provided to operators, and two wells have been drilled in areas 3 and 4 shown in Figure H1. Neither well has undergone adequate production testing at this date (August 2000) because of legal complications among the investors who funded the drilling programs.

As part of the technology transfer of the Waha-Lockridge field reservoir characterization, a CD-ROM containing 20 mi² of 3-D seismic data was produced and is now being distributed to Texas operators.

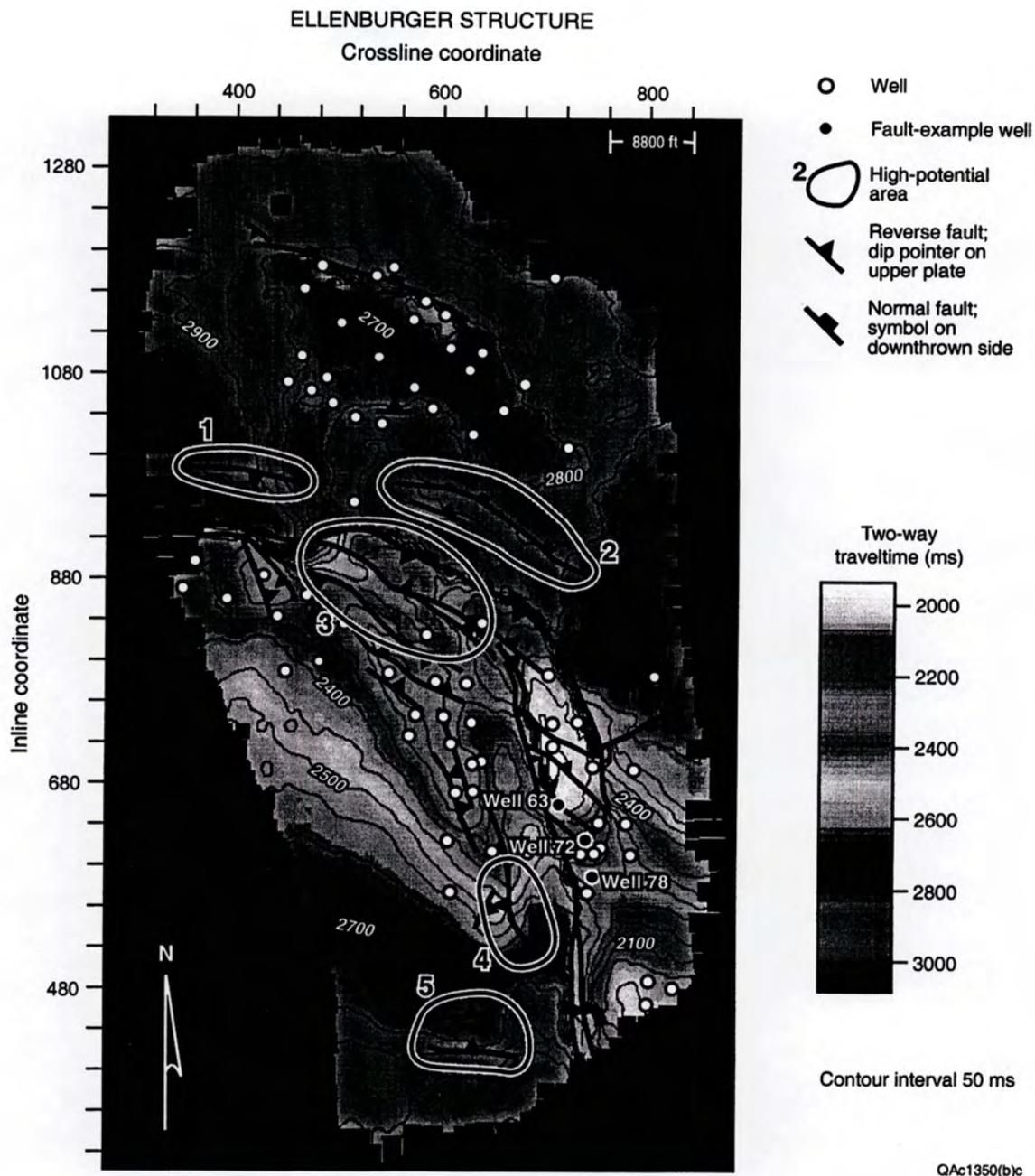


Figure H1. Seismic-interpreted Ellenburger structure map across Lockridge, Waha, and West Waha fields and recommended drilling areas. A color version of this map is available from the Bureau of Economic Geology if readers need to interpret the depth contours.

Appendix I. Corpus Christi Bay Fields

A multi-field study across Corpus Christi Bay was initiated in 1999 and is still in progress as of the date of this report (August 2000). State Lands partners in this work are Sabco Oil and Gas Corporation (operator) and Royal Exploration Company, Inc. (40-percent interest owner). Collectively, these two companies are the largest State Lands leaseholders in Corpus Christi Bay, with their major producing fields being Corpus Christi East, Corpus Christi NW, and Encinal Channel (fig. 6).

An extensive database of 50 mi² of 3-D seismic data, logs from 60 or more wells, and production history information from a large number of wells across the bay was shared with STARR researchers. Analyses of these data has already led to the drilling of the two step-out wells (53-6 and 48-7) shown in figure I1. These two wells are projected to produce more than 6 Bcf of gas (table 4), which will provide more than \$1.5 million to the Permanent School Fund.

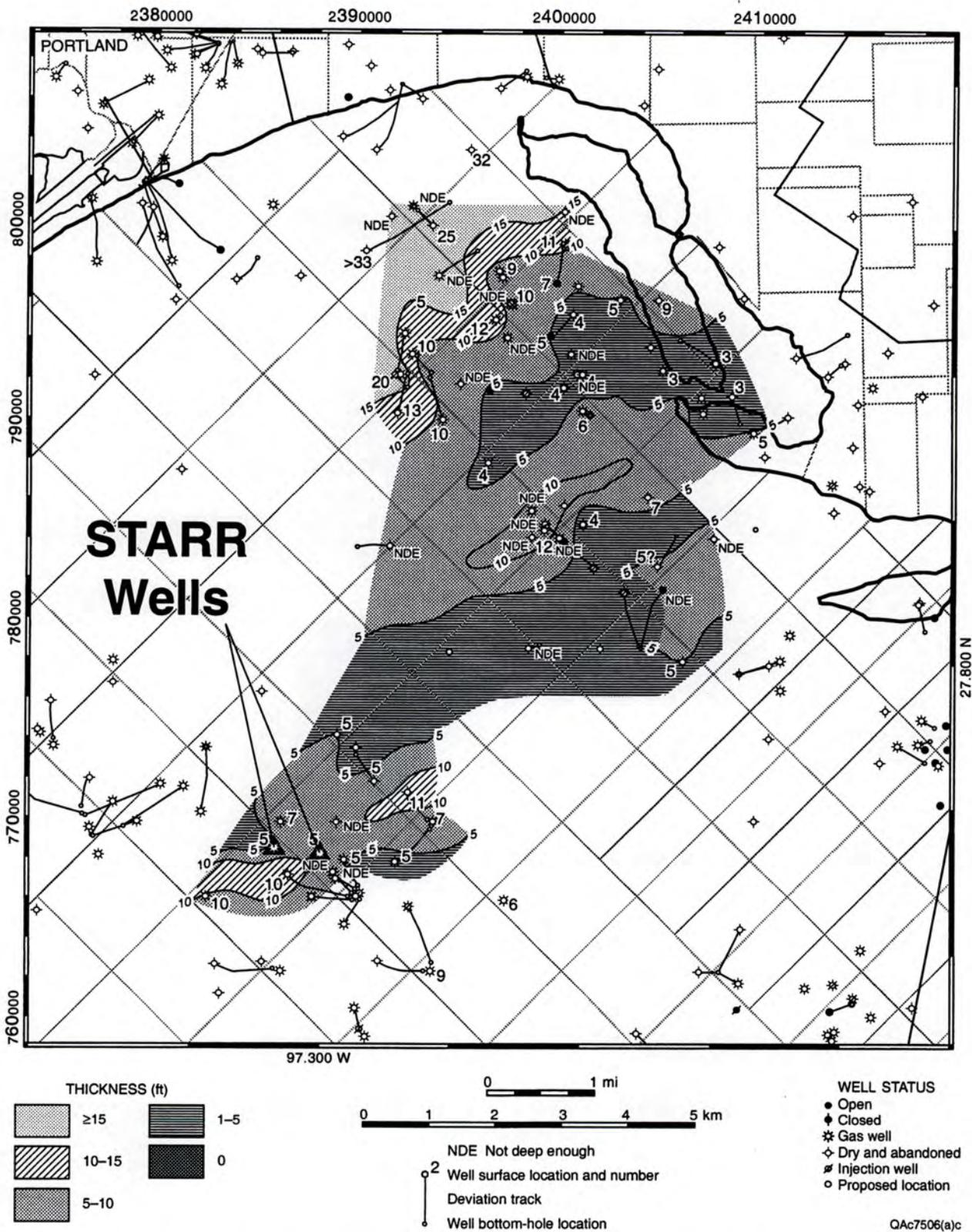


Figure 11. Location map of Corpus Christi East field, Nueces County, Texas. Map shows sand distribution at one of several producing intervals penetrated by two STARR wells (53-6 and 48-7).

Appendix J. Mustang Island 889 Field

The newest State Lands project is Mustang Island, Block 889 field (fig. 6). Sabco Oil and Gas, 100-percent owner of the field, has acquired permits for two new wells and requested STARR assistance to optimize the well locations. Analysis of the Sabco database has just started (August 2000).

Sabco plans to drill the first well in the fourth quarter of 2000. The second well is planned for mid-year 2001. Wells in the field have averaged about 30 Bcf of gas production; thus this project appears to be an excellent opportunity to create a significant increase in royalty income for the Permanent School Fund.

Appendix K. Project STARR Awards

Project STARR has been honored to receive several excellence in geoscience awards. These honors include Best Paper Awards at the Gulf Coast Association of Geological Societies (GCAGS) annual convention and at the West Texas Geological Society (WTGS) Fall Symposium. A Best Paper Award for “Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas” was presented to author George Asquith at the 1997 WTGS Fall Symposium, Midland, Texas; a Best Poster Award for “Project STARR—State of Texas Advanced Oil and Gas Resource and Recovery Program” was given to Roger Tyler at the 1997 GCAGS Convention, New Orleans, Louisiana; and a Best Paper Award for “Resources Optimization through Characterization of Dwindip Frio Shoreface/Shelf Sandstone Reservoirs: Red Fish Bay field, South Texas” was presented to Roger Barnaby at the 1994 GCAGS Convention, Austin, Texas.

Appendix L. STARR Publications

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Appendix M. STARR Workshops and Presentations

“Reservoir characterization and advanced resource recovery technology on Texas State Lands”: poster session presented at the Gulf Coast Association of Geological Societies Annual Convention, Corpus Christi, Texas, October 1998.

“STARR—The State of Texas Advanced Resource Recovery Program”: presented by Roger Tyler at the Society of Independent Professional Earth Scientists (SIPES) Convention, July 23, 1998, Durango, Colorado.

“State of Texas Advanced Resource Recovery Project (STARR)”: presented by Roger Tyler at the Railroad Commission of Texas, Regional Technology Transfer Conference, Midland, Texas, May 13, 1998.

“Integrated Strategies for Carbonate Reservoir Reserve Growth: An Example from the Ellenburger Group, Permian Basin, West Texas”: presented by R. P. Major, G. B. Asquith, B. A. Cain, B. A. Hardage, D. E. Lancaster, and H. Zeng: sponsored by the West Texas Geological Society, Midland, Texas, April 23, 1998, and Houston Geological Society, Houston, Texas, June 25, 1998.

“Reservoir Characterization of Keystone East Holt field; Modeling restricted platform carbonate”: presented by Mark Holtz at the Bureau of Economic Geology Seminar, April 22, 1998.

“Slope and Basin-Floor Depositional Systems, Ozona Sandstone, Val Verde Basin, Southwest Texas”: presented by Scott Hamlin at the Bureau of Economic Geology Seminar, April 15, 1998.

“State of Texas Advanced Resource Recovery Project (STARR)”: presented by Roger Tyler at the Railroad Commission of Texas, Regional Technology Transfer Conference, Houston, Texas, April 8, 1998.

“Reservoir Characterization of Keystone East Holt field”: presented by Mark Holtz at the Southwest Section of the American Association of Petroleum Geologists, March 31, 1998, Wichita Falls, Texas.

“Reservoir characterization of a deep-water channel-levee and lobe system, Bell Canyon Formation, Ford Geraldine Unit, West Texas (Delaware Basin)”: core display presented by S. P. Dutton on February 26, 1998, at the Permian Basin Section SEPM core workshop on DOE-Sponsored Studies of Permian Producing Fields, Midland, Texas.

“Incorporation of core data into reservoir characterization of a deep-water channel-levee and lobe deposit, Ford Geraldine Unit, Delaware Basin”: core display presented by S. P. Dutton at the Sixth Archie Conference on Improving Reservoir Productivity Using Static and Dynamic Delineation Methods, February 10, 1998, Kerrville, Texas.

“Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas”: presented by G. B. Asquith at the Permian Basin Well Log Society, January 15, 1998, Midland, Texas.

The “Reservoir Characterization Ford Geraldine Unit: Permian Bell Canyon Formation, West Texas” workshop was held on November 21, 1997, in Carlsbad, New Mexico. The workshop was followed by a two-day field trip titled “Facies Architecture of Submarine Channel-Levee and Lobe Sandstones: Permian Bell Canyon Formation, Delaware Mountains, West Texas.” The workshop and field trip were jointly sponsored by the U.S. Department of Energy, the State of Texas Advanced Resource Recovery Project, and the Petroleum Technology Transfer Council.

“Reservoir characterization of a deep-water channel-levee and lobe system, Bell Canyon Formation, Ford Geraldine Unit, West Texas (Delaware Basin)”: presented by S. P. Dutton to Texas Tech University, Geoscience Colloquium, November 14, 1997, Lubbock, Texas.

“State of Texas Advanced Oil and Gas Recovery Program—Project STARR”: presented by Roger Tyler at the Society of Independent Professional Earth Scientists, November 13, 1997, Austin, Texas.

“Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas”: presented by G. B. Asquith on November 12, 1997, at the Amarillo chapter of the Society of Professional Well Log Analysts, December 2, 1997, at The University of Texas at El Paso, and December 3, 1997, at New Mexico State University at Las Cruces.

“Reservoir characterization of channel-levee and lobe deposits Bell Canyon Formation, Geraldine Ford field, West Texas (Delaware Basin)”: presented by S. P. Dutton at the Bureau of Economic Geology Seminar, November 12, 1997.

“Reservoir characterization of Keystone East field, STARR Project”: presented by Mark Holtz at the West Texas Geological Society Fall Symposium, October 31, 1997, Midland, Texas.

"Methodology of 3-D computer modeling in restricted platform carbonate reservoirs, example from Keystone East Holt field": presented by Mark Holtz at the West Texas Society of Petroleum Engineers meeting, October 2, 1997, Midland, Texas.

"Reservoir Characterization of Permian Deep-Water Sandstones, Bell Canyon Formation, Geraldine Ford Area, West Texas (Delaware Basin)" was held in Midland in March 1997. This workshop was co-hosted by the West Texas Geological Society. It was attended by approximately 90 people, who received a set of workshop notes.

"Identifying Reserve Growth Potential through Integrated Geologic and Engineering Reservoir Characterization" was held at the 1996 Annual Convention of the Gulf Coast Association of Geological Societies (GCAGS) on October 2-4, 1996, in San Antonio, Texas. The short course provided an examination of subsurface reservoir analogs to the State Lands Gulf Coast and West Texas oil and gas reservoirs.

"Canyon Sandstones—a Geologically Complex Natural Gas Play in Slope and Basin Facies, Val Verde Basin, Southwest Texas": presented by Scott Hamlin to the South Texas Geological Society, San Antonio, Texas, March 1996.

