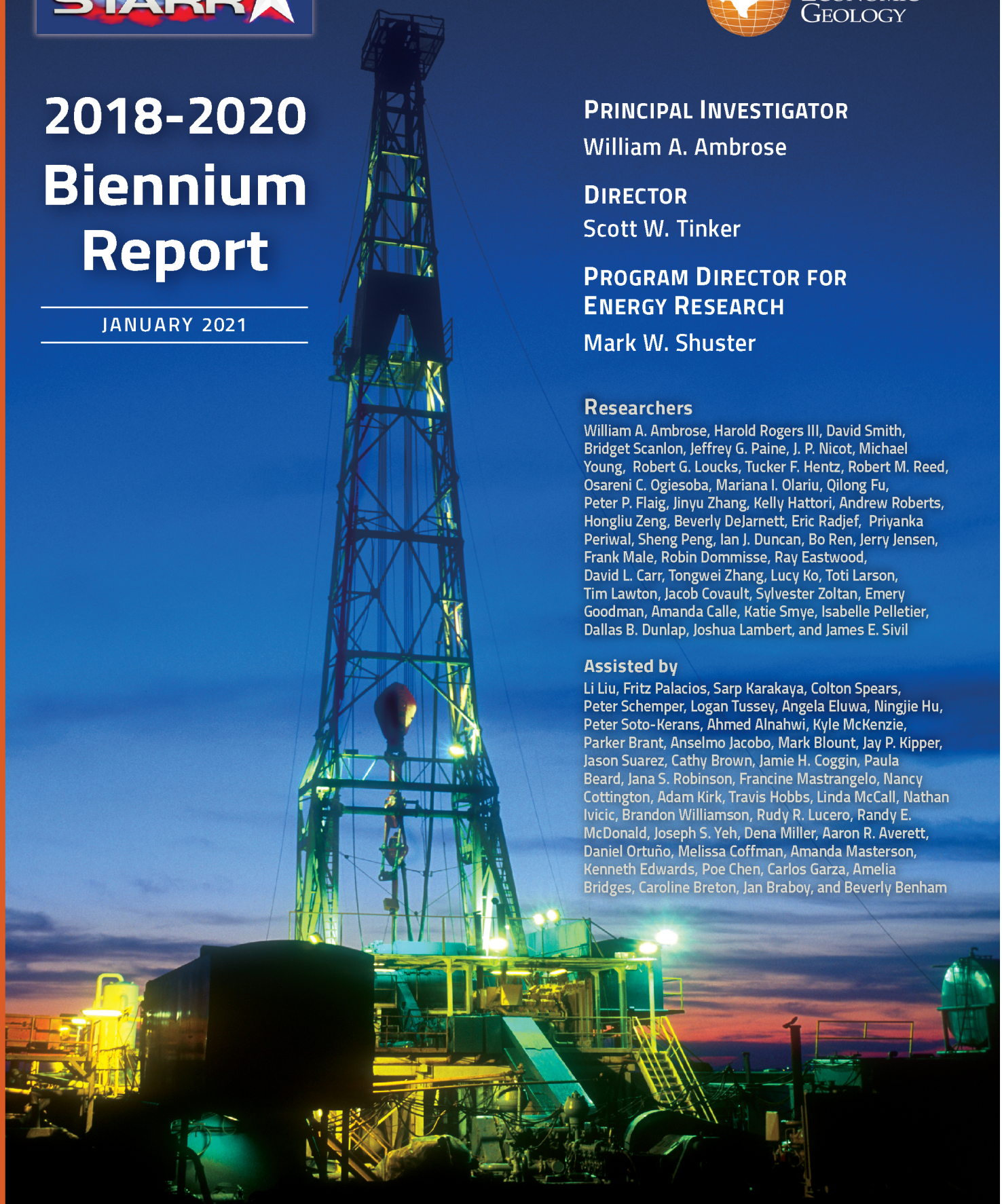
State of Texas Advanced Resource Recovery STARR

Bureau of Economic Geology

2018-2020 Biennium Report

JANUARY 2021



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STATE OF TEXAS ADVANCED RESOURCE RECOVERY PROGRAM (STARR)

2018-2020 BIENNIUM REPORT

January, 2021

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CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The main objective of the State of Texas Advanced Resource Recovery (STARR) program is to increase severance tax income for the State of Texas through research projects that promote the drilling of profitable oil and gas wells in the state. The Bureau of Economic Geology (BEG) receives funds from the State to conduct research that assists oil and gas operators in adding new or increasing existing production throughout Texas. Revenue associated with STARR projects must equal or exceed the amount appropriated to the program by the Legislature. This report summarizes accomplishments of the STARR program from September 1, 2018, to August 31, 2020.

Credit to the STARR program for the 2018–2020 biennium, in accordance with methodology approved by the State of Texas Comptroller's office, is approximately $91,039,900 (Table 1). Relative to total funding of $9.9 million over the current biennium, STARR is revenue positive by a factor of 8.1. To date, the STARR program has completed more than 60 field (reservoir characterization) studies and more than 30 regional studies. Figures 1 and 2 show the field and regional studies, respectively, that were active during the 2018–2020 biennium.

Table 1. Summary of royalty and severance tax revenue from September 1, 2018, through August 31, 2020.
Credit to the STARR program is in accordance with methodology approved by the Texas State Comptroller's office.

Regional Studies	Condensate (BBL)	Oil Well Head Value ($)	Oil Severance Tax (4.6%)	Gas (MCF)	Gas well head value ($)	Gas Severance Tax (7.5%)	Oil Severance (25%)	Gas Severance (25%)	Regional Studies Total Oil ($)	Regional Studies Total Gas ($)
Cotton Valley	69755	4,053,589.25	182,411.52	8,166,799.00	21,792,690.07	1,634,451.76	45,602.88	408,612.94	45,602.88	408,612.94
Eagle ford La Salle	33376957	1,693,014,167.53	76,185,637.54	239,688,452.00	564,224,747.42	42,316,856.06	19,046,409.38	10,579,214.01	19,046,409.38	10,579,214.01
Eagleford Buda Austin Chalk Del Rio	53,576,615	3,177,226,606.68	142,975,197.30	136,065,106	437,106,280.64	32,782,971.05	35,743,799.33	8,195,742.76	35,743,799.33	8,195,742.76
Glen Rose	68,074	3,933,373.85	177,001.82	397,993	1,283,849.53	96,288.71	44,250.46	24,072.18	44,250.46	24,072.18
Wilcox Greenhouse Deltas	243,314	16,085,373.02	723,841.79	952,770	3,374,247.24	253,068.54	180,960.45	63,267.14	180,960.45	63,267.14
Strawn	47,209	2,264,325.78	101,894.66	36,553	66,836.78	5,012.76	25,473.67	1,253.19	25,473.67	1,253.19
Upper Barnett	1,552,078	88,843,759.27	3,997,969.17	3,095,180	8,288,807.59	621,660.57	999,492.29	155,415.14	999,492.29	155,415.14
Wilcox Group Sed	164,602	9,802,303.70	4,441,103.67	3,920,208	12,128,706.04	909,652.95	110,275.92	227,413.24	110,275.92	227,413.24
Wolfcamp Reagan	50,761,412	2,950,585,948.73	132,776,367.69	206,375,790	567,635,127.25	42,572,634.54	33,194,091.92	10,643,158.64	33,194,091.92	10,643,158.64
Smackover	101	3,992.72	179.67	245	420.17	31.51	44.92	7.88	44.92	7.88
Dean Sandstone	11,304,990	515,955,661.37	23,218,004.76	14,600,364	29,832,778.56	2,237,458.39	5,804,501.19	559,364.60	5,804,501.19	559,364.60
Strawn Andy Roberts Regional	9,328	334,269.09	15,042.11	0	0.00	0.00	3,760.53	0.00	3,760.53	0.00
Wilcox Ambrose Zhang Olariu Flaig Regional	115,281	4,373,043.20	196,786.94	413,267	769,157.27	57,686.80	49,196.74	14,421.70	49,196.74	14,421.70
Strawn Flaig Regional	411,360	13,282,926.77	597,731.70	1,350,818	2,473,173.65	185,488.02	149,432.93	46,372.01	149,432.93	46,372.01
Cisco and Canyon Regional	331,307	16,503,983.53	742,679.26	191,339	419,045.01	31,428.38	185,669.81	7,857.09	185,669.81	7,857.09
Totals	152,032,383.00	8,496,263,324.49	386,331,849.60	615,254,884.00	1,649,395,867.22	123,704,690.04	95,582,962.42	30,926,172.52	70,343,946.92	19,718,935.23

Regional Revenue ($)	90,062,882.15

Field Studies	Condensate (BBL)	Oil Well Head Value ($)	Oil Severance Tax (4.6%)	Gas (MCF)	Gas well head value ($)	Gas Severance Tax (7.5%)	Oil Severance (100%)	Gas Severance (100%)	Field Studies Total Oil ($)	Field Studies Total Gas ($)
Ellenburger Winchester	982	69,177.50	3,112.99	2,157.00			778.25		778.25	0.00
Strawn Burnet	506	29,524.83	1,328.62	0.00	0.00	0.00	332.15	0.00	332.15	0.00
Tecolote	119927	7,052,856.29	317,378.53	2,008,106.00	5,017,452.28	376,308.92	79,344.63	94,077.23	79,344.63	94,077.23
Pantheon Woodbine	34,441	1,385,156.05	62,332.02	203,814	389,006.48	29,175.49	15,583.01	7,293.87	15,583.01	7,293.87
Caddo and Canyon groups Tannehill Daylight	10,154	422,519.00	19,013.36	0	0.00	0.00	4,753.34	0.00	4,753.34	0.00
Clearfork Surge	1,499,564	50,562,338.55	2,275,305.23	1,734,406	3,206,496.41	240,487.23	568,826.31	60,121.81	568,826.31	60,121.81
Strawn Afirmed	12,968	513,751.28	23,118.81	5,625	10,647.82	798.59	5,779.70	199.65	5,779.70	199.65
Cleveland Tecolote	55,220	2,991,838.49	134,632.73	500,234	1,175,591.23	88,169.34	33,658.18	22,042.34	33,658.18	22,042.34
Wilcox Hilcorp	1,518	74,880.87	3,369.64	2,112,250	4,449,212.28	333,690.92	842.41	83,422.73	842.41	83,422.73
Totals	1,735,280.00	63,102,042.86	2,839,591.93	6,566,592.00	14,248,406.50	1,068,630.49	709,897.98	267,157.63	709,897.98	267,157.63

* WTI - Cushing, Oklahoma

Field Revenue ($)	977,055.61
Regional Revenue ($)	90,062,882.15
Total Revenue ($)	91,039,937.76
Biennium Funding	9,900,000.00

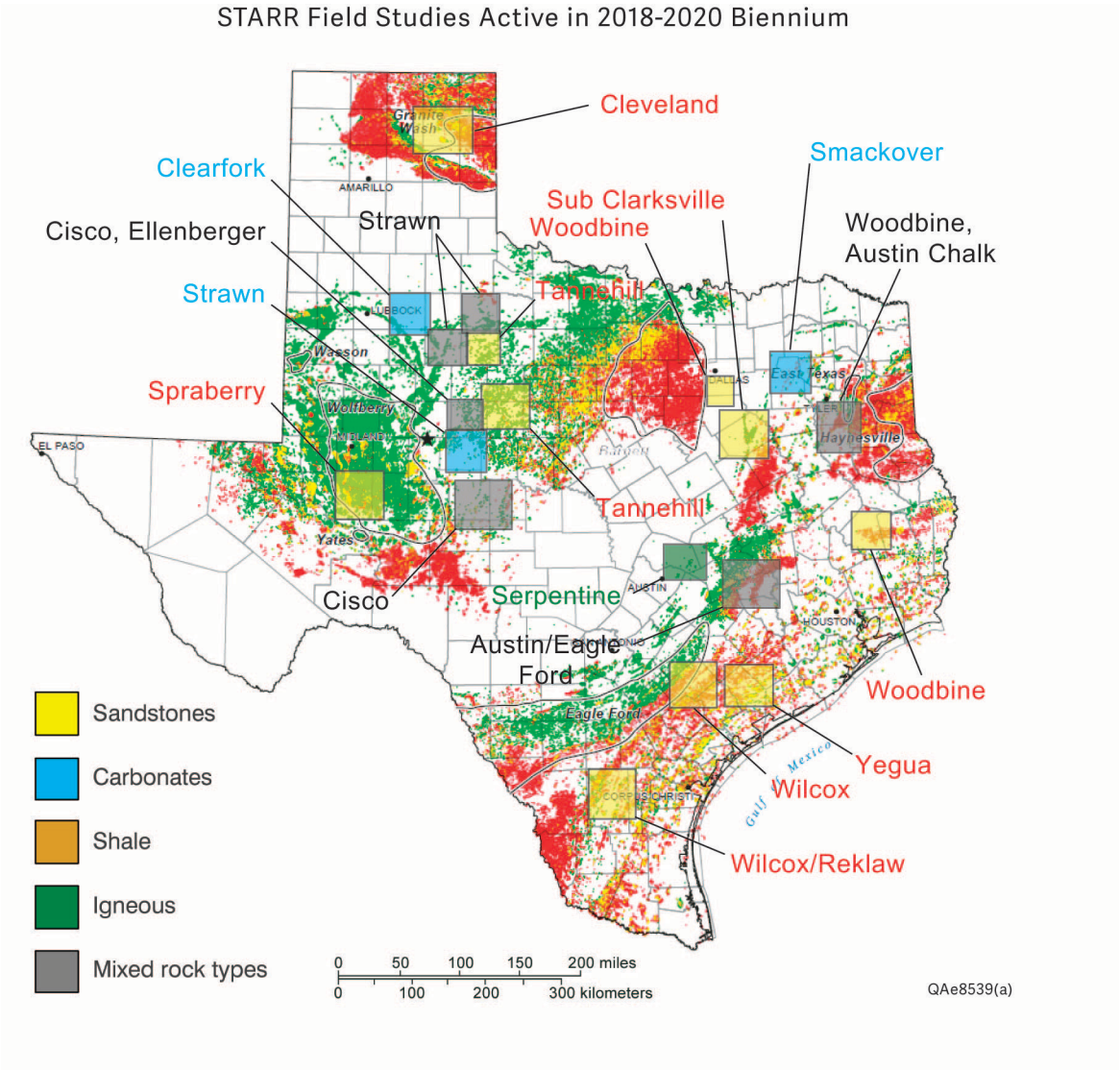

Figure 1. STARR field studies active in the 2018–2020 biennium. Color of rectangles and squares indicate dominant reservoir rock type: yellow (sandstone), blue (carbonate), brown (shale), green (igneous), and gray (mixed).

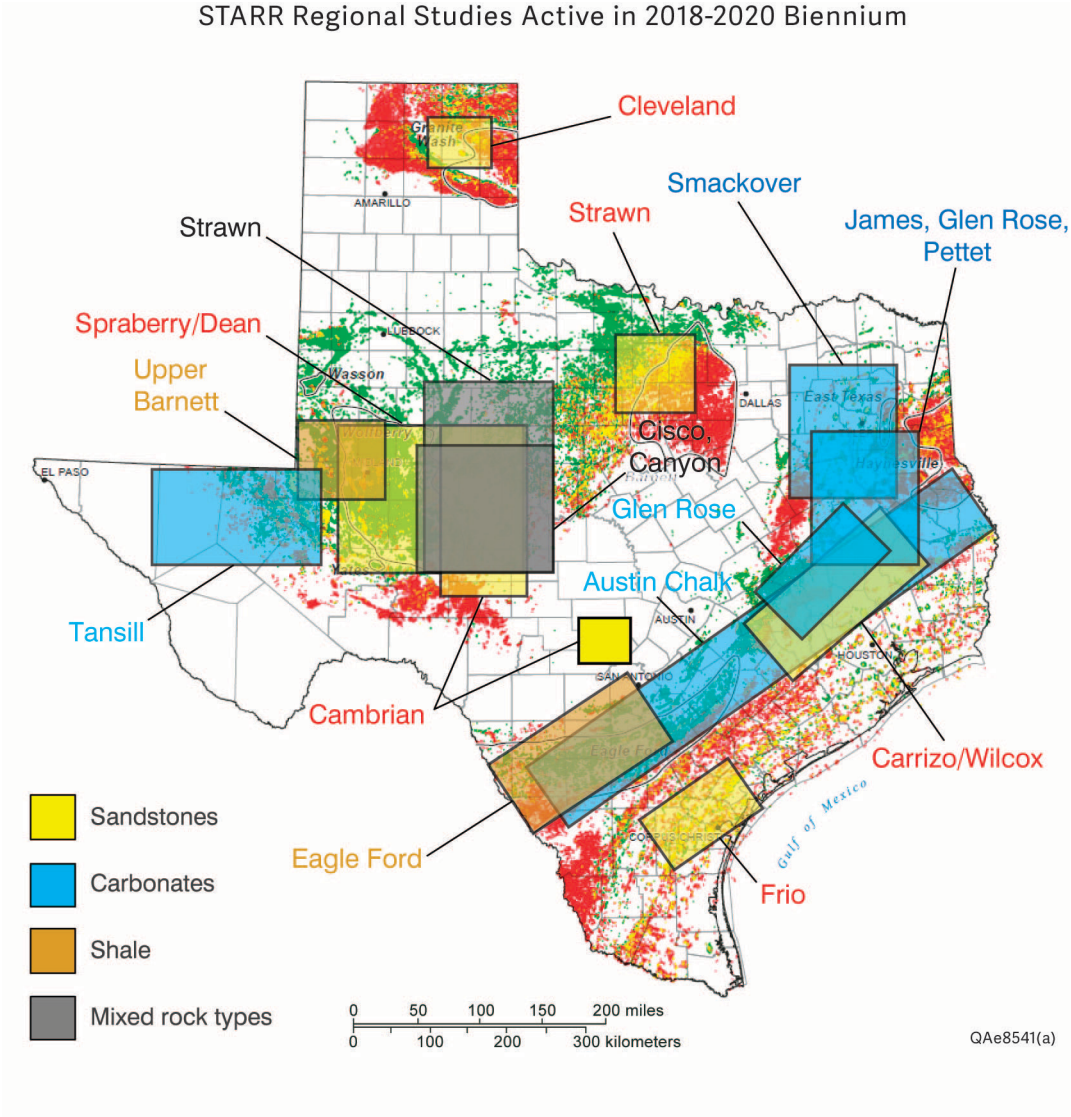

Figure 2. STARR regional studies active in the 2018–2020 biennium. Color of rectangles and squares indicate dominant reservoir rock type: yellow (sandstone), blue (carbonate), brown (shale), and gray (mixed).

Texas has produced more oil and natural gas than any other state. In 2018, Texas produced approximately 1.27 billion barrels of oil and 5.5 trillion cubic feet of gas. No other state or other region worldwide has been as heavily explored or drilled for oil and natural gas as Texas. In 2018, approximately 187,400 active oil wells and 98,700 active gas wells were producing oil and natural gas in the state (Texas Railroad Commission, 2020a and 2020b) (Fig. 3).

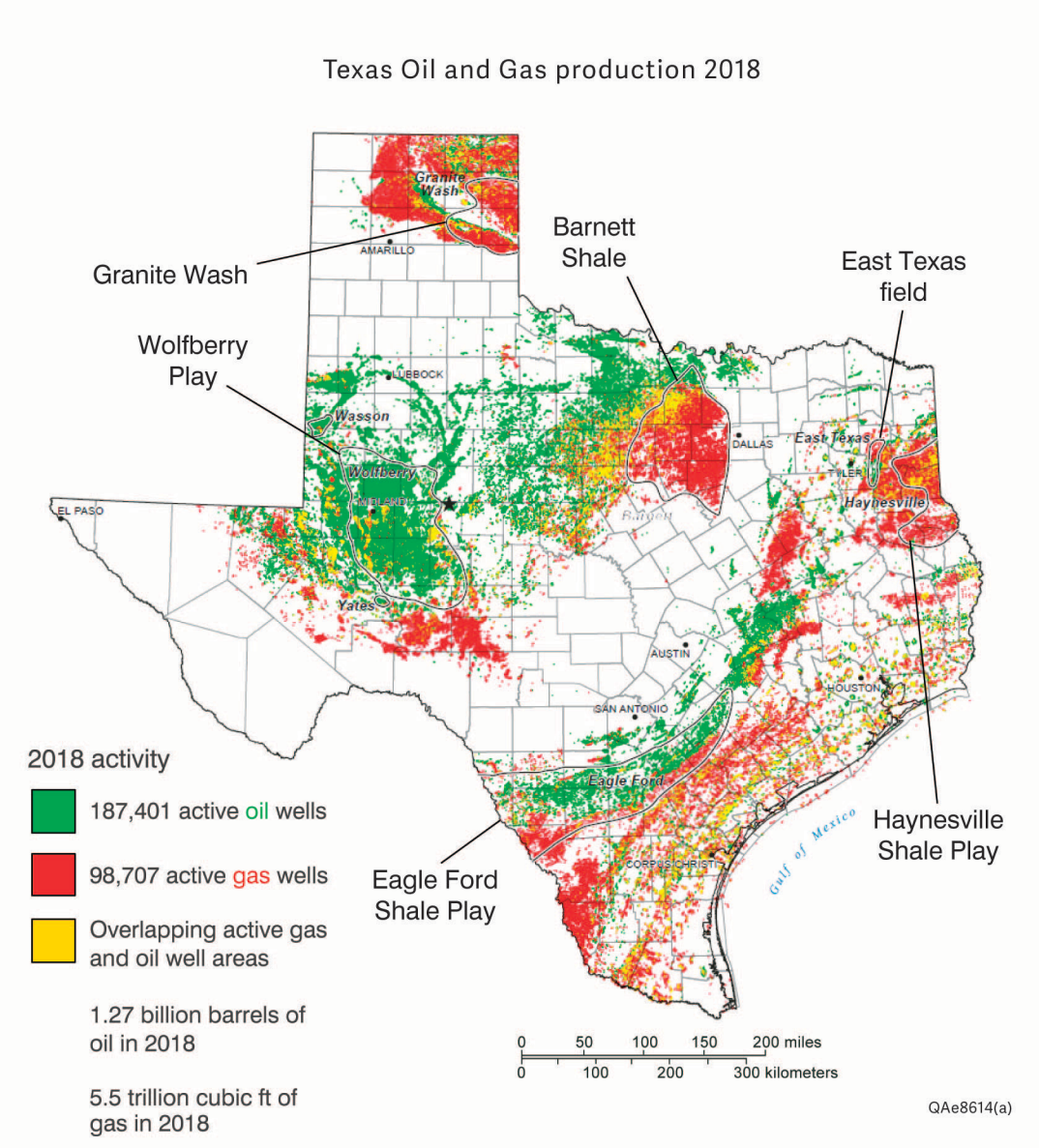

Figure 3. Oil and gas activity in Texas in 2018. Major oil and gas plays and East Texas field, the largest oil field in the Lower 48 U.S. in terms of original oil in place, are also shown. Well-distribution and production data are from the Texas Railroad Commission (2020a, b).

Many oil and gas companies benefit from STARR field and regional studies (see Letters of Cooperation [Appendix A]). STARR researchers provide technical support that leads to drilling opportunities for increased production and reserves. The STARR program provides a variety of research products that include core descriptions and interpretations, as well as subsurface lithology and structure maps from wireline-log data. STARR researchers also produce a host of research products from seismic data such as cross sections, inversion analyses, stratal-slice maps, and attribute maps. These research products help oil and gas operators to define new exploration and production targets from infill wells, recompletions, field extensions, redesigned waterfloods, EOR (enhanced oil recovery), and exploration wells in sparsely drilled areas outside of existing fields.

STARR has a technology-transfer approach that includes publications, presentations, and workshops. During the current 2018–2020 biennium, STARR researchers produced a variety of publications, presentations, and workshops. These items are summarized in Appendices B to D.

During the 2018–2020 biennium, STARR researchers gave several presentations and conducted reviews of core, wireline-log, and seismic data for industry partners. A partial list of recent and current STARR partners includes Surge Energy, Emerald Bay, Durango Resources, Petrotex Engineering Company, TECCorp International, Pantheon Oil and Gas, Carr Resources, Boardman Industries, Winchester Energy Limited, LLC, and Copeland Resources. A comprehensive list of oil and gas operators who have worked with STARR since 1995 is presented in Table 2.

Table 2. STARR field studies, 1995 to present.

Field	Operator	Period of Project STARR Interaction
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 and Mobil Oil (now ExxonMobil)	1996–1998
Bar Mar field	Hanson Corporation	1997–1998
Ozona field	Union Pacific Resources, Cross Timbers Oil Co.	1996-1999
Duval County Ranch field	Killam Oil	1998–1999
Umbrella Point field	Panaco, Incorporated	1995–1999
Red Fish Bay field (shallow Frio)	Pi Energy	1996–1997
Corpus Christi East field (Frio)	Sabco Oil and Gas, Royal Exploration	1998–2000
Corpus Christi NW field (Frio)	Sabco Oil and Gas, Royal Exploration	1998–2000
Encinal Channel field (Frio)	Sabco Oil and Gas, Royal Exploration	1999–2000
Mustang Island 889 field (Frio)	Sabco Oil and Gas	2000–2001
Red Fish Bay field (Middle Frio)	IBC Petroleum, Cinco	2001–2008
Red Fish Bay field (Deep Frio)	Boss Exploration, Cinco	2003–2008
Mustang Island Offshore (Frio)	Cabot Oil and Gas	2003
Northeast Red Fish Bay project (Frio)	Cabot Oil and Gas	2003
Laguna Madre (Frio)	Novus	2004–2005
Yates field EOR (Permian)	Kinder Morgan	2004–2006
Galveston Bay Shelf area study (Frio)	Santos USA Corp	2004–2006
Carancahua and Matagorda Bay projects (Frio, Miocene)	Brigham Exploration Company	2004–2008
West Bay area stud (Alligator Point field; Frio, Miocene)	Gulf Energy Exploration	2005–2007
LaSalle, Calhoun offshore (Frio)	Gulf Energy Exploration	2005–2007
Gold River North field (Olmos)	Huber	2006
Gold River North field (Olmos)	St. Mary's Land and Exploration	2007–2009
East Texas field (Woodbine)	Various operators	2006–2008
North Newark field (Barnett)	Various operators	2007–2009
Spur Lake and Broken Bone fields	Gunn Oil Co.	2007–2009
Mustang Island (Frio)	Sabco Operating Co.	2006–2008
Copano Bay	MPG Petroleum	2007–2009
East Texas field (Moncrief lease)	Danmark Energy	2007–2009
Sugarkane field	Texas Crude	2006–2008
Cleveland/Marmaton/Atoka field	Jones Energy, Ltd.	2008–2010
Lavaca Bay field	Neumin Production Company	2008–2010
Alabama Ferry field	Antioch Energy LLC	2009–2011
Haynesville	Petrohawk, Common Resources, BP	2009–2011
Spraberry/Wolfcamp (Midland County)	Pioneer Resources	2010–2012
Lavaca Bay field (Frio)	Neumin Production Co.	2010–2012
Eliasville/Breckinridge fields (Caddo Limestone)	BASA Resources	2011–2013
Dismukes field (Dimmit County: Austin Chalk/Eagle Ford Shale)	CML Exploration	2011-2013

Field	Operator	Period of Project STARR Interaction
Sugar Creek field (Austin Chalk/Woodbine)	BBX Operating	2011–2013
Double A Wells field (Woodbine)	Vision Resources	2011–2013
K-R-S field (Marble Falls Limestone)	Cobra Oil and Gas, Stalker Energy	2011–2013
Bend Conglomerate (Wise County)	Devon Energy	2011–2013
La Sara field (Frio)	Risco La Sara Operations	2011–2013
Ranger Limestone (Eastland County)	Stalker Energy	2011–2013
Austin Chalk (Dimmit County)	Newfield Exploration Company	2011–2013
Frio Formation (Refugio County)	T-C Oil Company	2012–2014
Cleveland/Marmaton/Granite Wash (Hemphill Co.)	Devon Resources, Arête Resources	2012–2014
Woodbine Group (Leon County)	Risco La Sara Operations, Chesapeake Energy	2012–2014
Woodbine Group (Walker County)	Chesapeake Energy	2012–2014
Cisco Limestone (Tom Green County)	AEATX	2012–2014
Pearsall Formation (McMullen, Dimmit Co.)	Valence, Devon	2012–2014
San Angelo Sandstone (Irion County)	Renda Energy	2012–2014
Atoka/Cherokee Group (Ochiltree, Lipscomb, Hemphill Counties)	Arête Resources	2012–2014
Mississippian Lime (Shackelford, Stephens, Throckmorton, Young Counties)	Tracker Resources	2012–2014
Glorieta Group (Ward County)	Whiting Resources	2012–2014
Harkey, Swastika, Cline Woodbine/Eagle Ford (Polk County)	BP	2012–-2014
Woodbine Group (Tyler County)	BP	2012–2014
ClearFork Formation (Iatan field)	BASA Resources	2013–2015
Buda Limestone (Dimmit County)	US Enercorp	2013–2015
Tonkawa, Douglas Formations (Hemphill Co.)	Chesapeake Energy	2013–2015
Woodbine Group (AA Wells, Hortense fields)	Apache Corporation	2013–2015
Pettet Limestone (Anderson County)	Arête Resources	2013–2015
Woodbine Group (East Texas field)	Zone Energy	2013–2015
Woodbine Group (Kerens, South field)	Five Star Energy	2013–2015
Wilcox Group (Bee, Goliad Counties)	Excellong	2013–2015
Wolfcamp Formation (Howard County)	Excellong	2013–2015
Eaglebine Trend (Fayette County)	Devon Resources	2014–2016
Marble Falls Formation (Jack County)	Atlas Resource Partners	2014–2016
ClearFork/Spraberry/Wolfcamp (Howard, Borden, Scurry Counties)	Harmonia Inc.	2014–2016
Wilcox Group (Bee County)	Formosa Petrochemical	2014–2016
Douglas/Tonkawa Formations (Lipscomb Co.)	Jones Energy	2014–2016
Wilcox Group (Lavaca County)	Imagine Resources LLC	2014–2016
Spraberry/Dean/Wolfcamp (Howard County)	Haimo America Inc.	2015–2017
Nowack/Thrall (Williamson County)	Trinity Brothers	2015–2017
Serbin (Bastrop/Lee Counties)	Riley Exploration	2015–2017
Wolfcamp Formation (Howard County)	Anadarko Petroleum	2016–2018
Thrall (Williamson County)	Patriot Operating Co.	2016–2018
Ellenburger (Nolan County)	Winchester Energy Limited	2016–2018
San Miguel/Olmos (Maverick County)	Endeavor Natural Gas LP	2016–2018
Smackover Formation (Rains County)	Dyersdale Energy	2016–2018
Reinecke Horseshoe Atoll (Borden County)	Harmonia. Inc.	2016–2018

Field	Operator	Period of Project STARR Interaction
Cleveland Formation (Hansford County)	Latigo Producing	2016–2018
Austin Chalk/Eagleford (Fayette County)	Oak Spring Energy	2016–2018
Wilcox/Carrizo (Grimes County)	Prolifico Exploration	2016–2018
Austin Chalk (Jasper County)	Fourhorses LLC	2016–2018
Tannehill Sandstone (Nolan/Taylor Co.)	TrayCon Exploration	2016–2018
Spraberry Formation (Reagan/Martin Counties)	De la Terra Exploration	2016–2018
Wilcox/Reklaw (Duval County)	Stalker Energy	2016–2018
Bend Conglomerate (Jack County)	TECCorp International	2017–2019
Wilcox Group (Dewitt County)	Copeland Resources	2017–2019
Tannehill Formation (Nolan/Taylor/Coke Co.)	Teal Exploration	2018–2020
Woodbine Group (Polk County)	Petrotex	2018–2020
Strawn Group (Knox County)	Tri-Star Petroleum Company	2018–2020
Cleveland Formation (Lipscomb/Ochiltree Co.)	Tecolote, Inc.	2019–
Taylor Group (Williamson County)	Boardman Industries	2019–
Ellenburger Group (Kendall County)	Starcreek Energy	2019–
Wilcox Group (Zapata County)	Hilcorp	2019–
Frio Formation (Nueces/San Patricio Counties)	Durango Resources	2019–
Yegua Formation (Jackson County)	Emerald Bay Exploration	2019–
Caddo/Canyon/Tannehill (Knox County)	Daylight Petroleum	2019–
Strawn/Tannehill (King County)	Burnett Oil	2019–
Strawn Group (Coke/Nolan Counties)	Affirmed Resources	2020–
Clearfork Formation (Crosby County)	Surge Energy	2020–
Cisco and Strawn Groups (Nolan County)	Winchester Energy Limited	2020–
Woodbine Group (Polk County)	Pantheon Oil and Gas	2020–
Hope Sand (Concho County)	SCAL, Inc.	2020–
Pearsall Formation (Maverick County)	Tony Ortiz Production Services	2020–
Strawn Group (Scurry County)	Carr Resources	2020–

STARR REVENUE-NEUTRALITY METRICS

An important goal of the STARR program is to demonstrate revenue neutrality STARR's revenue neutrality is calculated over a period of two years. Royalties and severance taxes for the State are the basis for revenue-neutrality calculations (Table 3). This metrics table was developed in conjunction with the Texas State Comptroller's office in 2004.

Revenue values summarized in Table 1 are derived from total production in areas defined by field and regional studies during the 2018–2020 biennium. Total revenue value is defined as all new production multiplied by the price of oil and gas for a given month and totaled from oil and gas well head value. STARR involvement in regional plays allows the Bureau of Economic Geology to sum up 25% of the severance tax, whereas severance-tax credit for STARR field studies are at a 100% value (Table 3). The Total revenue in Table 1 is the summation of this process for every regional and field study in the current biennium.

Table 3. STARR revenue-neutrality metrics.

Type of STARR recommendation	Expiration period following recommendation (Initial/incremental production must begin before recommendation expires)	Time period for credit following initial production	Royalty credit	Severance tax credit
1. Drilling new infill or step-out well in established field	4 years	2 years	100%	100%
2. Drilling new infill or step-out well in established field with multiple reservoir intervals	4 years	2 years following completion of each additional reservoir interval	100%	100%
3. Recompletion—missed pay well in established field	4 years	2 years	100%	100%
4. Enhanced oil recovery (EOR) field project	4 years	2 years following date selected by STARR within a 5-year period from initial operator action	100% of incremental production	100% of incremental production
5. Exploration well	4 years	2 years	100%	100%
5.a. Subsequent development wells following discovery of new field	2 years following initial production from exploration well	2 years	100%	100%
5.b. Copycat wells following discovery of new field	2 years following initial production from exploration well	2 years	25%	25%
6. Wells drilled on basis of influence of regional trend studies	4 years starting 6 months after releasing study	2 years	25%	25%

Note: Royalty credit accrues only from production on State GLO (General Land Office) Lands. Severance tax credit accrues from all other oil and gas production in Texas.

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APPENDIX A

Letters of Cooperation

The following selected letters are from partner companies with whom the STARR program has recently collaborated. These letters document the strong interaction between STARR and the oil and gas industry.

SURGE ENERGY AMERICA

7850 North Sam Houston Parkway W
Houston, TX 78705

Dr. William Ambrose March 30, 2020

Project Director
STARR Program
Bureau of Economic Geology
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Dear Dr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas development programs in the Clear Fork Formation in the Hoople Field, currently owned and operated by Surge Energy America, LLC in Crosby County, Texas, by core presentation, sampling, examination and analysis carried out by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. Specifically, we would like to acknowledge the great help Dr. Qilong Fu, Dr. Hongliu, Zeng, and yourself offered during the course of core examination.

The core examination and diagenesis study by the Bureau has contributed significantly to our understanding of controls on reservoir quality and hydrocarbon accumulation in the Clear Fork formation in this part of Texas in general, and in the Hoople Field in particular. We hope that the STARR program will continue to receive funding from the State of Texas. We are a small independent oil company, the results of the Bureau's research on various methods of exploitation and development has been very helpful in our efforts to discover additional reserves and extract more oil out of the ground in the state. The facilities and core warehousing that the STARR project possesses are very helpful. Having your staff to present the core in a very convenient way for us to examine, Dr. Fu's expertise and knowledge about the Clear Fork formation in this part of the Permian basin, made our trip more enjoyable and valuable

The STARR program continues to help companies like us turn academic research into economic success especially in our new waterflooding program. We would recommend the STARR program to other companies.

Sincerely,

Xijin (CJ) Liu, Ph.D

Chief Geologist

WINCHESTER
ENERGY LIMITED

Two Riverway Suite 1700 || Houston TX 77056 USA || Phone: +1 713 -333-0610

William Ambrose April 1, 2020

Project Director
STARR Program
Bureau of Economic Geology
The University of Texas at Austin
P. O. Box X
University Station
Austin, Texas 78713-8924

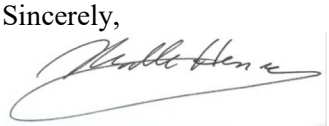
Dear Mr. Ambrose:

I would like to acknowledge the continuous contributions that you and your institution, the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology, have made to Winchester Energy' exploration and development program over many years and recently with the Cisco Formation in Nolan County, Texas and also your past assistance in understanding Karst development in the Ellenburger.

The research work by the Bureau, specifically, core descriptions/interpretations and net-sandstone maps of the Cisco Group in Lake Trammel South field has contributed to our understanding of controls on reservoir quality and hydrocarbon accumulation in key areas in this part of Texas. We hope that the STARR program will continue to receive funding from the State of Texas. Being of a small size with limited resources, we and other independent companies do not have the benefit of major geologic research programs and therefore, results of the Bureau's research on various methods of exploitation and development has been very helpful in our efforts to discover additional reserves in the state. We have also been able to educate many others as to the facilities and core warehousing that the STARR project possesses. Having their Austin staff meticulously walk us through cores from the past helped us understand this reservoir even better.

The Bureau's studies, publications and presentations have provided an education and insight to many recent advances in petroleum exploitation that has been successfully applied to our areas of interest. The STARR program continues to help companies like us turn academic studies into economic success especially through our new completion processes.

Sincerely,



Neville Henry
Managing Director
Winchester Energy Ltd

Daylight Petroleum, LLC
P.O. Box 52070 Houston, TX 77052
281-601-1252 (Office)

William Ambrose April 1, 2020

Project Director
STARR Program
Bureau of Economic Geology
The University of Texas at Austin
P. O. Box X
University Station
Austin, Texas 78713-8924

Dear Mr. Ambrose:

I would like to thank you and the Bureau of Economic Geology for their contribution to Daylight Petroleum and our objectives. Your donations have played a vital role in understanding the subsurface framework associated with the paleo depositional environments of North-West Texas.

The State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology, through core and subsurface mapping, are indeed advantageous to our long-term company goals. The research provided from STARR has helped up better understand the geological aspects of the Canyon Group, Caddo Sand, and Tannehill Sand in North Texas. As a low risk company, we rely on risk mitigation through means of in-house efforts, acquired well history and research provided by groups such as the BEG.

I hope the STARR program continues to receive the necessary funding to continue their vital research that is much needed across our industry. These regional studies have aided our efforts in understanding the lithology, reservoir properties and subsurface modeling of the previously mentioned formations located in Knox County, Texas. In turn, they have also provided us with stronger insight into fulfilling our future capital projects program. This program would potentially consist of infill well locations and enhanced recovery projects.

I anticipate that the STARR Program will continue its efforts and persist in applying them to the benefit of the oil and gas industry. The crossroads where high academic standards meet industry efforts can be essential to gaining mutual benefits by increasing American oil production while simultaneously supporting applied educational programs.

Sincerely,

Clint Walker
Geologist
Daylight Petroleum

C. David Copeland
President

"20 Years in Project Research, Evaluation, & Funding."

Mr. William Ambrose

April 3, 2020

Project Director
STARR Program
Bureau of Economic Geology
The University of Texas at Austin

Dear Mr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas development program in the Wilcox Thin-bed sands project which our company is researching in Dewitt County, Texas. It's potential for development has been greatly enhanced by research carried out by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology.

We continue to study information provided by the STARR program as we approach the science side of our project. As a small company we do not have access to the vast data bases, as well as experienced staff, which your group brings to the table. We certainly do encourage the state to continue to fund the STARR program as we encourage other companies to use their services.

Sincerely,
C. Dave Copeland
President
Copeland
Resources, Inc.
Copeland
Remote Sensing,
LLC

Cell 512.917.7260 Dave@CopelandResources.com
CopelandResources.com
PO Box 170943
Austin, TX 78717

April 9, 2020

CHARLES E. NAGEL III

William Ambrose - Project Director
STARR Program
Bureau of Economic Geology
The University of Texas at Austin
P. O. Box X University Station
Austin, Texas 78713-8924

Dear Mr. Ambrose:

Burnett Oil Co. would like to thank and acknowledge your team for the great job they have done to help us understand several target formations in King County, Texas by research carried out through the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology.

Detailed core descriptions with petrology reports have greatly added to our understanding of the depositional systems controlling Strawn lime and Tannehill sand reservoirs. Additionally, geochemical research by the Bureau has contributed to our insight into the hydrocarbon sourcing and distribution within many of the stacked opportunities along our productive trend. Lastly, the diligent work being performed by your team on seismic conditioning and inversion is helping us understand the capabilities and limitations of our seismic dataset in this area. We hope to continue this great partnership in King County and will consider working with you on other assets as they come into our portfolio. As a small independent operator, we value programs like this that help expand our technical understanding of a play by partnerships with expert collaborators for the purpose of efficient exploration and development of mineral interests. We hope that the STARR program will continue to receive funding from the State of Texas. In the meantime, we will continue to use the facilities and core warehousing that the STARR project offers us and recommend this program to other operators with similar goals.

Texas-based operators like Burnett Oil Co. appreciate programs like the STARR project because such support gives us confidence and a sense of pride born from the legislative backing to our industry who has driven the economy of our state for many years.

Sincerely,

DocuSigned by:
Charles E. Nagel III
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APPENDIX B

STARR Publications

One of the major goals of Project STARR is to disseminate results and new concepts developed by the program. During current reporting biennium (September 1, 2018 to August 31, 2020), STARR researchers generated a wide variety of publications.

Alnahwi, A., Loucks, R. G., Ruppel, S. C., Scott, R. W., and Tribovillard, N., 2018, Dip-related changes in stratigraphic architecture and associated sedimentological and geochemical variability in the Upper Cretaceous Eagle Ford Group in south Texas: AAPG Bulletin, v. 102, no. 12, p. 2537–2568.

Alnahwi, A., and Loucks, R. G., 2019, Mineralogical composition and total organic carbon quantification using X-ray fluorescence data from the Upper Cretaceous Eagle Ford Group in southern Texas: AAPG Bulletin, v. 103, no. 12, p. 2891–2907.

Alnahwi, A., Kosanke, T., Loucks, R. G., Greene, J., Liu, X., and Linton, P., 2020, High-resolution hyperspectral-based continuous mineralogical and total organic carbon analysis of the Eagle Ford Group and associated formations in south Texas: AAPG Bulletin, v. 104, no. 7, p. 1439–1462.

Ambrose, W. A., and Dutton, S. P., 2018, Depositional and diagenetic controls on reservoir quality in deepwater sandstones in the Lower Wilcox Group, Lavaca Canyon Complex in the Hallettsville Embayment, southeastern Texas Gulf Coast: GCAGS Journal, v. 7, p. 1–20.

Ambrose, W. A., and Hentz, T. F., 2019, Outcrop to subsurface linkages, Canyon and Cisco Groups, Eastern Shelf of the Permian Basin: AAPG Search and Discovery Article No. 11216, 29 p.

Ambrose, W. A., and Loucks, R. G., 2019, Transition from paleosols in the Cenomanian Woodbine Group to carbonates in the Coniacian lower Austin Chalk in East Texas field: an example of compressed transgressive succession from subaerial processes to deepwater deposition: GCAGS Journal, v. 8, p. 1–21.

Hattori, K. E., Loucks, R. G., and Kerans, C., 2019, Stratal architecture of a halokinetically controlled patch reef complex and implications for reservoir quality: a case study from the Aptian James Limestone in the Fairway Field, East Texas Basin: Sedimentary Geology, v. 387, p. 87–103.

Hentz, T. F., and Ambrose, W. A., 2019, Lowstand deltas and incised valleys of the Tannehill sandstone (Cisco Group) of the southern Eastern Shelf of the Permian Basin, West Texas: GCAGS Transactions, v. 69, p. 97–110.

Ko, L., Ruppel, S. C., Loucks, R. G., Hackley, P. C., Zhang, T., and Shao, D., 2018, Pore-types and pore-network evolution in Upper Devonian-Lower Mississippian Woodford and Mississippian Barnett mudstones: insights from laboratory thermal maturation and organic petrology: International Journal of Coal Geology, v. 190, p. 3–28.

Loucks, R. G., 2018, Domal, thrombolitic, microbialite biostromes and associated lithofacies in the Upper Albian Devils River Trend along the northern, high-energy margin of the Maverick Basin: Sedimentary Geology, v. 371, p. 75–88.

Loucks, R. G., 2018, Eagle Ford–A depositional setting and processes in southwestern Texas: an example of deeper-water, below-storm-wave-base carbonate sedimentation on a drowned shelf: GCAGS Journal, v. 7, p. 59–78.

Loucks, R. G., Poros, Z., and Machel, H. G., 2018, Characterization, origin, and significance of carbonate pulverulite: a weathering product of microporous strata: GCAGS Journal, v. 7, p. 79–92.

Loucks, R. G., 2019, Pore networks and reservoir-quality trends in Lower Cretaceous carbonates of the northern rim of the Gulf of Mexico: substantiating reservoir-quality risk factors: GCAGS Journal, v. 8, p. 35–56.

Loucks, R. G., and Dutton, S. P., 2019, Insights into deep, onshore Gulf of Mexico Wilcox sandstone pore networks and reservoir quality through the integration of petrographic, porosity and permeability, and mercury injection capillary pressure analyses: AAPG Bulletin, v. 103, no. 3, p. 745–765.

Loucks, R. G., Gates, B. G., and Zahm, C. K., 2019, Depositional systems, lithofacies, nanopore to micropore matrix network, and reservoir quality of the Upper Cretaceous (Cenomanian) Buda Limestone in Dimmit County, southwestern Texas: GCAGS Journal, v. 8, p. 281–300.

Mauck, J. V., Loucks, R. G., and Entzminger, D. J., 2018, Stratigraphic architecture, depositional systems, and lithofacies of the Mississippian upper Barnett Two Finger Sand Interval, Midland Basin, Texas: GCAGS Journal, v. 7, p. 21–45.

Male, F., and Duncan, I. J., 2019, Lessons for machine learning from the analysis of porosity-permeability transforms for carbonate reservoirs: Journal of Petroleum Science and Engineering, p. 106825.

Ogiesoba, O. C., Ambrose, W. A., and Loucks, R. G., 2018, Application of instantaneous-frequency attribute and gamma-ray wireline logs in the delineation of lithology in Serbin field, Southeast Texas: a case study: Interpretation, v. 6, no. 4, p. T1023–T1043.

Ogiesoba, O. C., Ambrose, W. A., and Loucks, R. G., 2019, Investigation of seismic attributes, depositional environments, and hydrocarbon sweet-spot distribution in the Serbin field, Taylor Formation, Southeast Texas: Interpretation, v. 7, no. 1, p. T49–T66.

Ogiesoba, O. C., and Eluwa, A. K., 2019, Comparison of structural styles observed in upper Eocene (Jackson Group) and Oligocene (Vicksburg Group) strata within the Rio Grande and Houston Embayments southwest and northeast of the San Marcos Arch, Refugio and Calhoun Counties, South Texas Gulf Coast: GCAGS Journal, v. 8, p. 170–190.

Olariu, M. I., and Zeng, H., 2018, Prograding muddy shelves in the Paleogene Wilcox deltas, south Texas Gulf Coast: Marine and Petroleum Geology, v. 91, p. 71–88.

Peng, S., 2019, Gas relative permeability and its evolution during water imbibition in unconventional reservoir rocks: direct laboratory measurement and a conceptual model: SPE Reservoir Evaluation & Engineering, v. 22, no. 4, p. 1346–1359.

Peng, S., Reed, R. M., Xiao, X., Yang, Y., and Liu, Y., 2019, Tracer-guided characterization of dominant pore networks and implications for permeability and wettability in shale: Journal of Geophysical Research: Solid Earth, v. 124, p. 1459–1479.

Peng, S., Ren, B., and Meng, M., 2019, Quantifying the influence of fractures for more-accurate laboratory measurement of shale matrix permeability using a modified gas-expansion method: SPE Reservoir Evaluation & Engineering, v. 22, no. 4, p. 1293–1304.

Reed, R. M., Sivil, J. E., Sun, X., and Ruppel, S. C., 2019, Heterogeneity of microscale lithology and pore systems in an Upper Cretaceous Eagle Ford Group horizontal core, South Texas, U.S.A.: GCAGS Journal, v, 8, p. 22–34.

Ren, B., and Duncan, I., 2019, Modeling oil saturation evolution in residual oil zones: implications for CO2 EOR and sequestration: Journal of Petroleum Science and Engineering, v. 177, p. 528–539.

Ren, B., and Duncan, I. J., 2019, Reservoir simulation of carbon storage associated with CO2 EOR in residual oil zones, San Andres formation of West Texas, Permian Basin, USA: Energy, v. 167, p. 391–401.

Zeng, H., Zhang, J., and Ambrose, W. A., 2019, Sediment dispersal patterns and paleoshoreline trajectory of Wilcox Group, South-Central Texas Coast: GCAGS Transactions, v. 69, p. 431–435.

Zhang, J., Rossi, V. M., Peng, Y., Steel, R., and Ambrose, W. A., 2019, Revisiting late Paleocene lower Wilcox deltas, Gulf of Mexico: river-dominated or mixed-process deltas?: Sedimentary Geology, v. 389, p. 1–12.

APPENDIX C

STARR Presentations

One of the major goals of the STARR program is to disseminate results and new concepts in oil and gas research. During the first sixteen months of the current reporting biennium (2018–2020), STARR researchers gave a variety of presentations to oil and gas operators, a vital outreach activity impacting new oil and gas production in Texas.

Ambrose, W. A., State of Texas advanced oil and gas resource recovery program: presented at the 89th Panhandle Producers & Royalty Owners Association, Amarillo, Texas, September 20, 2018.

Ambrose, W. A., State of Texas Advanced oil and gas resource recovery program: presented to the Texas Governor's Office of Economic Development and Tourism, Austin, Texas, October 4, 2018.

Ambrose, W. A., Canyon and Cisco Groups in the Eastern Shelf of the Permian Basin from outcrop to subsurface: presented to North Texas Geological Society, Wichita Falls, Texas, November 15, 2018.

Ambrose, W. A., Outcrop to subsurface linkages, Canyon and Cisco Groups, Eastern Shelf of the Permian Basin: presented at the Southwest Section of the American Association of Petroleum Geologists, Irving, Texas, April 9, 2019.

Ambrose, W. A., Oil and gas in Texas: the STARR program: presented at the 10th East Texas Energy Symposium, Kilgore, Texas, May 7, 2019.

Ambrose, W. A., State of Texas advanced oil and gas resource recovery: presented at the Bureau of Economic Geology 3E Research Symposium, Austin, Texas, October 18, 2019.

Ambrose, W. A., Transition from paleosols in the Woodbine Group to carbonates in the Austin Chalk, East Texas Field: A compressed transgressive succession from subaerial processes to deepwater deposition: presented at the 69th Annual GCAGS Conference, Houston, Texas, October 24, 2019.

Carr, D. L., Wolfberry and Wolfbone resource assessment: outcrop and core to geocellular models and economic outlooks: presented at the West Texas Geological Society Fall Symposium, Midland, Texas, September 26, 2018.

Hattori, K., Halokinetically mediated stratal architecture of the Aptian James limestone in the Fairway field, East Texas: assessing evolution and variability in a shoaling patch reef complex in a salt basin: presented to the American Association of Petroleum Geologists, University of Texas at Austin Chapter, Austin, Texas, February 1, 2019.

Hattori, K., New model for halokinetically controlled patch reef systems: a case study from the Fairway field, a major Aptian reservoir in the East Texas Basin: presented at the American Association of Petroleum Geologists National Convention, San Antonio, Texas, May 20, 2019.

Hentz, T. F., Cleveland and Marmaton Tight-gas sandstones: sequence framework, depositional facies, and production trends, Northwest Anadarko Basin: presented to Tecolote Energy, Austin, Texas, February 12, 2019.

Hentz, T. F., Lowstand deltas and incised valleys of the Tannehill sandstone (Cisco Group) of the southern Eastern Shelf of the Permian Basin, West Texas: presented at the Southwest Section of the American Association of Petroleum Geologists, Irving, Texas, April 8-9, 2019.

Hentz, T. F., Shelf-to-basin architecture and depositional trends, Missourian-Wolfcampian strata of the Eastern Shelf of the southern Midland Basin, West Texas: presented at the American Association of Petroleum Geologists National Convention, San Antonio, Texas, May 21, 2019.

Hentz, T. F., Lowstand deltas and incised valleys of the Tannehill sandstone (Cisco Group) of the southern Eastern Shelf of the Permian Basin, West Texas: presented at the 69th Annual GCAGS Convention, Houston, Texas, October 24, 2019.

Loucks, R. G., Characterization, origin, and significance of carbonate pulverulite: a weathering product of microporous strata: presented at the 68th Annual GCAGS Convention, Shreveport, Louisiana, September 30, 2018.

Loucks, R. G., Eagle Ford-A depositional setting and processes in southwestern Texas: an example of deeper-water, below-storm-wave-base carbonate sedimentation on a drowned shelf, presented at the 68th Annual GCAGS Convention, Shreveport, Louisiana, September 30, 2018.

Loucks, R. G., How depositional environment, diagenesis, and thermal maturity affect the evolution and significance of organic and mineral pore systems in unconventional oil and gas reservoirs: current understanding and future research: presented at the American Association of Petroleum Geologists Hedberg Conference, Houston, Texas, March 4, 2019.

Loucks, R. G., Origin and characterization of the lithofacies and dual micropore/macropore network in Pennsylvanian (Early Desmoinesian) Caddo shelf-buildup complexes, Stephens County, North-Central Texas: presented to the Abilene Geological Society, Abilene, Texas, March 21, 2019.

Loucks, R. G., New model for halokinetically controlled patch reef systems: a case study from the Fairway field, a major Aptian reservoir in the East Texas Basin: presented at the American Association of Petroleum Geologists Annual Convention, San Antonio, Texas, May 20, 2019.

Loucks, R. G., A type cored section for the Upper Cretaceous Austin Chalk Group in South Texas; Getty No. 1 Lloyd Hurt Well, LaSalle County, Texas: presented at the American Association of Petroleum Geologists Annual Convention, San Antonio, Texas, May 20, 2019.

Loucks, R. G., Depositional systems, lithofacies, nanopore to micropore matrix network, and reservoir quality of the Upper Cretaceous (Cenomanian) Buda Limestone in Dimmit County, southwestern Texas: presented at the 69th Annual GCAGS Convention, Houston, Texas, October 24, 2019.

Ogiesoba, O. C., Application of instantaneous frequency attributes and gamma-ray wireline logs in the delineation of lithology in Serbin Field, Southeast Texas: A Case Study: presented to the Society of Exploration Geophysicists, 88th SEG International Exposition and Annual Meeting, Anaheim, California, October 15, 2018.

Ogiesoba, O. C., Comparison of structural styles observed in Upper Eocene (Jackson Group) and Oligocene (Vicksburg Group) strata within the Rio Grande and Houston Embayments, southwest and northeast of the San Marcos Arch, Refugio and Calhoun Counties, South Texas Gulf Coast, presented at the 69th Annual GCAGS Convention, Houston, Texas, October 24, 2019.

Olariu, M. I., Muddy shorelines of the Paleogene Wilcox Deltas, South Texas Gulf Coast: presented at the Bureau of Economic Geology 3E Research Symposium, Austin, Texas, October 18, 2019.

Olariu, M. I., Early Miocene High Island delta system, offshore Texas and Louisiana: presented at the American Association of Petroleum Geologists Annual Convention, San Antonio, Texas, May 20, 2019.

Peng, S., A reliable and fast method of accurate measurement of shale matrix permeability: presented to Schlumberger Reservoir Laboratories, Houston, Texas, February 1, 2019.

Peng, S., Tracer-guided characterization of dominant pore network and implications on permeability and wettability in shale: presented at the American Association of Petroleum Geologists Annual Convention, San Antonio, Texas, May 21, 2019.

Peng, S., Gas relative permeability and evolution during water imbibition in unconventional reservoir rocks: direct laboratory measurement and a conceptual model: presented at the Unconventional Resources Technology Conference, Denver, Colorado, July 22, 2019.

Peng, S., Water/oil displacement by spontaneous imbibition through multiscale imaging and implication on wettability in Wolfcamp Shale: presented at the Unconventional Resources Technology Conference, Denver, Colorado, July 22, 2019.

Rogers, H. III, Calculating the boundary of oil fields in Texas using Python in a GIS Workflow: presented at the 2019 Texas GIS Forum, J. J. Pickle Research Campus, The University of Texas at Austin, October 23, 2019.

Zeng, H., Linear combination and RGB blending of frequency panels for 3D facies and reservoir characterization: presented at the Society of Exploration Geophysicists (SEG) 2018 Annual Meeting Workshop: Frequency Dependent Seismic Analysis Including Processing and Modeling and Interpretation, Anaheim, California, October 19, 2018.

Zeng, H., Challenges to use morphology (shape) as a seismic attribute: can machine learning help?: presented at the Society of Exploration Geophysicists (SEG) Annual Meeting Workshop, San Antonio, Texas, September 27, 2019.

Zeng, H., Seismic-informed high-resolution sedimentology: filling the gap between exploration and production: presented to Surge Oil Company, Houston, Texas, October 24, 2019.

Zeng, H., Sediment dispersal patterns and paleoshoreline trajectory of Wilcox Group, South-Central Texas Coast, presented at the 69th Annual GCAGS Convention, Houston, Texas, October 24, 2019.

APPENDIX D

STARR Workshops and Guidebooks

Brown, L. F., Jr., Ambrose, W. A., Hentz, T. F., and Carr, D. L., 2018, Guidebook to the Pennsylvanian System of North-Central Texas: Bureau of Economic Geology, Jackson School of Geosciences and the Austin Geological Society, Field Trip Guidebook, 49 p.

Olariu, M. I., Ambrose, W. A., Olariu, C., Steel, R., and Zhang, J., 2018, Depositional history and architectural variability of the Wilcox Group in Texas: Bureau of Economic Geology and Austin Geological Society, Core Workshop Guidebook, no. SW0024.

ADDITIONAL PROGRAM ELEMENTS

STARR Water/Energy Nexus

Part 1 – Produced Water from Oil and Gas Operations

Overview and Goals of Project

Water is a critical issue in energy development in Texas. Managing water for oil and gas development in the state is a challenge, both sourcing water for hydraulic fracturing and impacts on groundwater depletion and managing produced water to reduce seismicity. Our past work has allowed us to assess impacts of produced water management on induced seismicity and showed that shallow disposal in plays outside of Oklahoma might explain the relatively low levels of seismicity. However, shallow disposal may result in overpressuring in these units and could cause contamination of overlying aquifers. There is increasing interest in Texas to beneficially reuse produced water for sectors outside of oil and gas, including irrigation and aquifer recharge. The STARR program has provided support to help us address these issues. The support has also allowed us to participate in various programs, including the New Mexico Produced Water Research Consortium focusing on treatment of produced water in the Permian Basin. We have provided presentations to many groups throughout the year to provide the quantitative data to support different options for managing water for the energy sector in Texas. The STARR funding complements funding from industry (ExxonMobil) and foundations (Sloan and Mitchell Foundations) and allowed us to expand our program to address specific issues within the state. The program has allowed us to develop new sources of funding with the Texas Water Development Board and the U.S. Geological Survey to provide more detailed quantitative data on water use for energy development in Texas with projections for the next 50 years.

Description of Results and Findings

Our recent work addressed the following questions:

1. Might future water demands for hydraulic fracturing exceed water supplies?
2. Might produced water management become a limiting factor for unconventional oil and gas production?
3. What strategies can help to mitigate water demand for hydraulic fracturing and produced water management issues?

Our results show that large increases in water use for hydraulic fracturing over the past decade, particularly in the Permian Basin. These volumes represented about 30% of water use in other sectors in the Permian Basin. Large depletion in groundwater storage was recorded in the Eagle Ford play (up to ~60 ft/yr). Projected water use for hydraulic fracturing would exceed planned groundwater depletion in some parts of the Eagle Ford and Permian Basin plays. We also estimated future produced water volumes in the plays. The highest is the Permian Basin, representing ~ two times the water use in Texas in 2017. The study suggested that water

management could be substantially improved by closing the loop through reusing of produced water for hydraulic fracturing of new wells. This process would partially mitigate groundwater depletion and potential induced seismicity. However, the projected produced water volumes in the Permian Basin exceeds projected water demand for hydraulic fracturing by almost four times; therefore, other approaches will be required to manage this excess produced water.

A second study that we conducted examined the potential for beneficially using produced water outside of the oil and gas sector. This analysis suggests that high irrigation water demand would benefit from using treated produced water rather than depleting groundwater resources in the Permian Basin. In addition, the treated produced water could be used to recharge some of the depleted aquifers in the Permian Basin, including the Ogallala and Pecos Valley aquifers. The Starr Water Economics program has provided support to analyze many produced water samples from the Permian Basin. These analyses indicate that some of the produced water from the Wolfcamp unit in the Delaware Basin has relatively low salinity (< 50,000 mg/L Total Dissolved Solids) that could be treated with reverse osmosis, which is less expensive than thermal desalination.

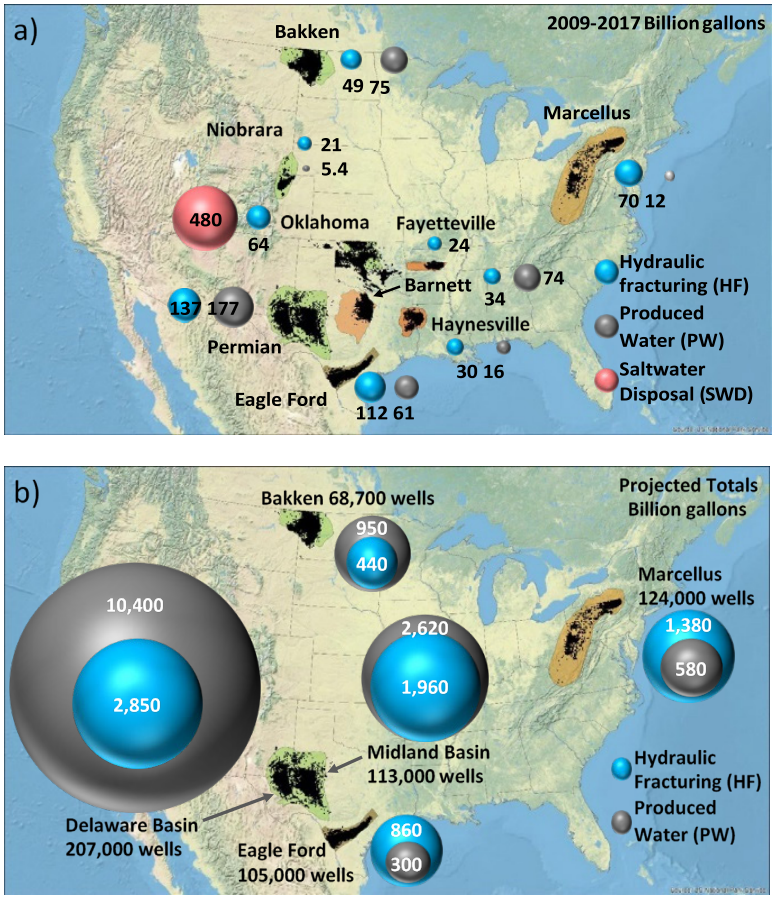

Figure 4. (a) Historical water use for hydraulic fracturing and produced water volumes along with saltwater disposal throughout the U.S. and (b) projections of future water demand for hydraulic fracturing and produced water volumes over the life of the plays (~ 50 yr).

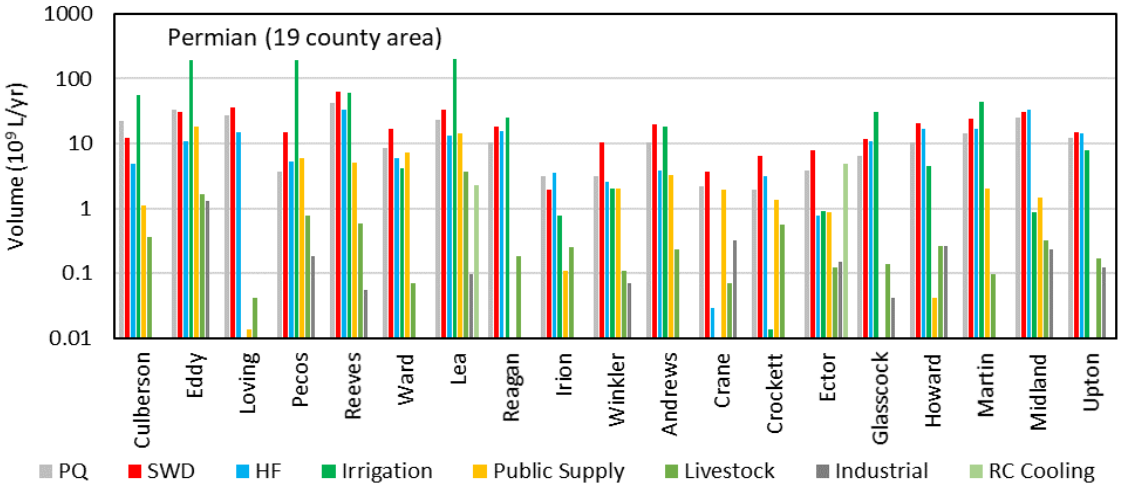

Figure 5. Comparison of produced water (PQ), salt water disposal (SWD), hydraulic fracturing water demand (HF) in 2017 relative to water demand for irrigation, public supply, livestock, industrial and power plant cooling in 2015 in the main counties in the Permian Basin.

Products and Outcomes (Partial List)

Lemons, C. R., G. McDaid, K. M. Smye, J. P. Acevedo, P. H. Hennings, D. A. Banerji, and B. R. Scanlon (2019), Spatiotemporal and stratigraphic trends in salt-water disposal practices of the Permian Basin, Texas and New Mexico, United States, *Environmental Geosciences*, *26*(4), 107-124.

Nicot, J.-P., R. Darvari, P. Eichhubl, B. R. Scanlon, B. A. Elliott, L. T. Bryndzia, J. F. W. Gale, and A. Fall (2020), Origin of low salinity, high volume produced waters in the Wolfcamp Shale (Permian), Delaware Basin, USA, *Applied Geochemistry*, *122*, 104771.

Scanlon, B. R., S. Ikonnikova, Q. Yang, and R. C. Reedy (2020), Will water issues constrain oil and gas production in the U.S.?, *Env. Sci. & Technol.*, *https://pubs.acs.org/doi/10.1021/acs.est.9b06390*.

Scanlon, B. R., R. C. Reedy, P. E. Xu, M., J. P. Nicot, D. Yoxtheimer, Q. Yang, and S. Ikonnikova (2020), Can we beneficially reuse produced water from oil and gas extraction in the U.S.?, *Science of the Total Environment*, *https://doi.org/10.1016/j.scitotenv.2020.137085*.

Presentations

Scanlon, B. R. (2019), Water Management Strategies both within and outside the Oil sector based on data from all Major Plays within the U.S., *Presentation to Am. Petrol. Industry, Webinar, Feb. 25, 2020.*

Scanlon, B.R. (2020), Can we Optimize Water Management in the Permian Basin to Minimize Adverse Environmental Impacts, New Mexico Produced Water Research Consortium, Jan. 15, 2020.
Scanlon, B.R. (2020), Cumulative Water Risks related to Oil and Gas Development, Webinar Society of Petroleum Engineering, June 6, 2020.
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Scanlon, B. R. (2019), Managing Produced Water in Texas, *Presentation to the Railroad Commission of Texas, Dec. 17, 2019*.
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STARR Water/Energy Nexus

Part 2 – Water Use and Seismicity

Overview and Goals of Project

For the last several years, water/energy research by the BEG in the State of Texas has focused on several specific areas, including water use in drilling and hydraulic fracturing operations, disposal of wastewater through UIC Class II wells, and the potential that wastewater disposal might induce earthquakes. Wastewater management remains a significant issue in Texas. Though disposal of produced water through UIC wells is still the dominant management option, treatment technologies and other management options are being developed. Any decisions related to water management need to be balanced by unintended consequences, especially if the water is used for other beneficial purposes, like irrigation or release into surface water bodies—other STARR projects are assessing these issues. The STARR Water/Energy project continues to provide support for broad participation on the issues of induced seismicity (water/energy) from wastewater disposal and landscape impacts (land/energy) from energy development of all types (oil and gas, solar, and wind). For example, research focused on the Texas Panhandle is linking disposal volumes and intervals to historical and recent earthquake activity (see Fig. 6 from Acevedo et al., submitted). Results show that the rate of events ($M \geq 2.5$) increased almost 3-fold, from 1.21 to 3.50 events per year, in the periods before and after 2008, respectively. STARR continues to leverage support from external grants to operate the Regional Induced Seismicity Collaborative (RISC), a consortium of five states (TX, OK, KS, NM, AR) addressing seismicity within their borders. RISC is currently running the Nation's only webinar series dedicated to understanding induced seismicity for a broad array of stakeholders ranging from regulators to operators to interested members of the public. Related to land impacts, especially in west Texas, STARR continues to leverage externally-funded research that helps us understand impacts to land assets from energy infrastructure and construction and to design ways to mitigate impacts in the future. For example, STARR augmented a grant from the Cynthia and George Mitchell Foundation to participate in the Respect Big Bend study, an award-winning program dedicated to communicating science-based information to land owners and energy companies, so that they can improve the decisions made on their lands.

Examples of Results and Findings

Water/Energy

- The earthquake research pro-gram at BEG, known as TexNet-CISR and dual funded by private operators and the State of Texas, has quickly become a national leader in operational seismology, providing data to RRC, operators, and the public. Re-searchers have published dozens of papers and bulletins during this biennium.

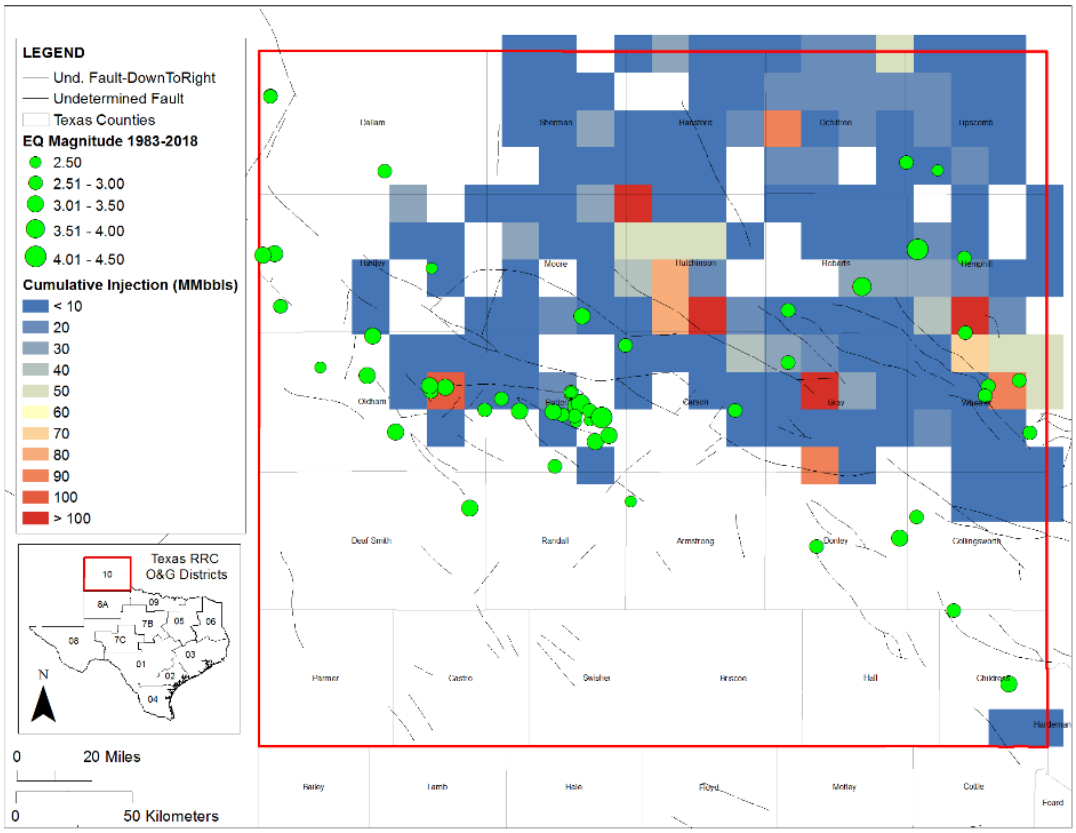

Figure 6. Recent (1983 to 2018) earthquake magnitudes and cumulative fluid injection in the Texas Panhandle.

Land/Energy

- Research focus during this biennium was on the Permian Basin, where we assessed historical and potential future land impacts from O&G, solar, and wind energy development.
- The area of interest was 169,000 km^2), or about that of Wisconsin.
- Oil and gas development is the dominant source of landscape alteration in the region, just given historical activities. The graphic at right (Fig. 7 [Pierre et al. 2020]) shows possible future scenarios, assuming high drilling activity and 1 well/pad.
- A study by Smith et al. (2020) reported that restoration of historical and future altered lands could require more than 1.3M pounds of seeds. Studies to assess lands impacted by renewable energy development are ongoing.

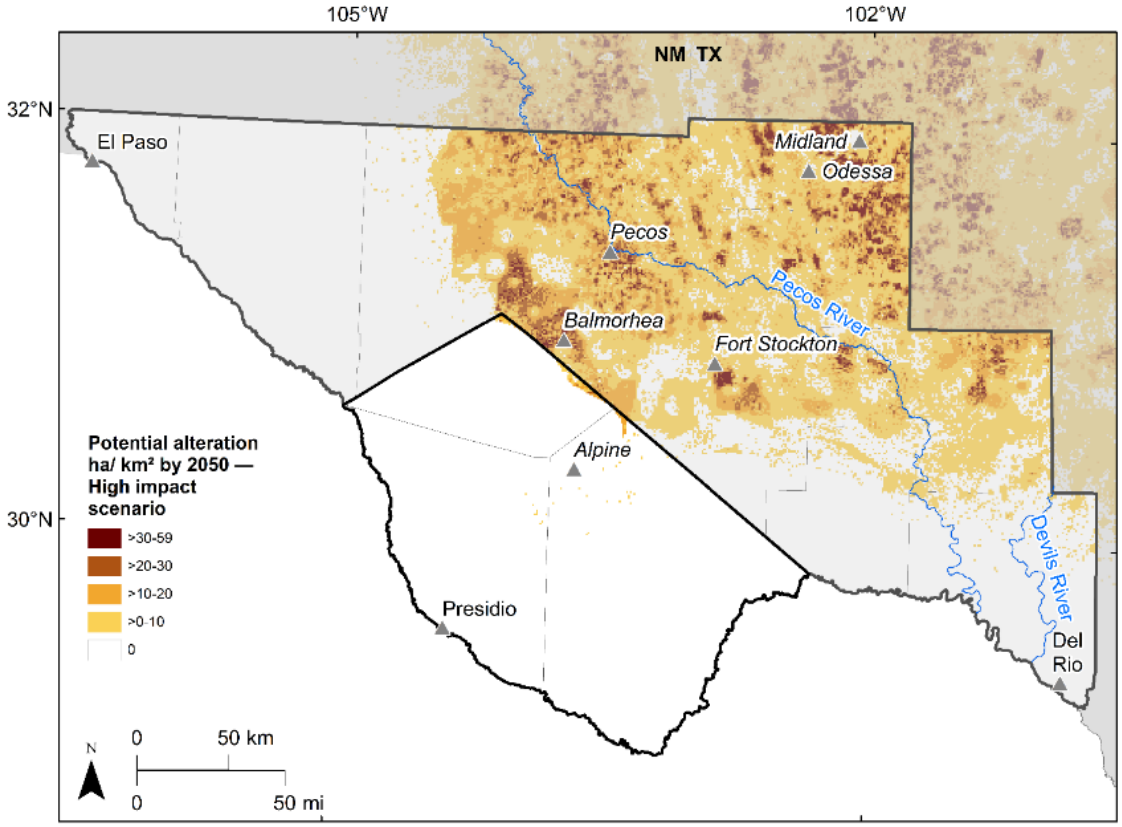

Figure 7. Possible future scenarios of landscape alteration in oil- and gas-producing areas in Trans-Pecos Texas (from Pierre et al., 2020).

Products and Outcomes (partial list)

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- Pierre, J.P. J. R. Andrews, M.H. Young, A.Y. Sun, B.D. Wolaver. 2020. Projected Landscape Impacts from Oil and Gas Development Scenarios in the Permian Basin, USA. Env. Mgmt. doi:10.1007/s00267-020-01308-2.
- Devitt, D.A., M.H. Young, J.P. Pierre. 2020. Assessing the potential for greater solar development in West Texas, USA. Energy Strategy Review. Vol. 29. doi:10.1016/j.esr.2020.100490.
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- Smith, F.S., J.P. Pierre, M.H. Young, D.A. Devitt. 2020. Estimation of Future Native Seed Demand for Restoration of Oil and Gas-Energy Sprawl in West Texas, USA. Ecol. Restor. Accepted.

Connection to Neutrality and Value to Texas

STARR funds continue to leverage and match external grants in two different programs. In the water/energy program, 17 companies have sponsored the CISR consortium at a total of $1,275,000 per year, and the US Dept. Energy sponsored the RISC program at $250,000 per year. In the land/energy program, the Cynthia and George Mitchell Foundation underwrote two studies at ~$400,000 to support the Respect Big Bend initiative to assess potential impacts to land resources from all energy infrastructure, primarily in the Delaware Basin. The Bureau of Economic Geology continues to focus on water disposal practices to manage earthquakes in Texas, and on land use practices to improve land quality for future generations of Texas land owners. Together, these programs represent a leveraging of approximately 10:1, and they remain vital for maintaining the quality of Texas' resources.

STARR Hazards Mapping and Response

Overview and Goals

Multiple geologic hazards impact Texas citizens, infrastructure, and economic development. Principal among these are coastal erosion, tropical-cyclone impact, sinkhole development, and landslides. Goals of the STARR Hazards program are to prepare the state to respond to hazards by understanding their location and severity, assessing the threat they pose, and ultimately producing an atlas of geologic hazards that is accessible to emergency responders, planners, and citizens.

Description of Results and Findings

Efforts in this biennium were focused on coastal-hazard mapping as part of the 2019 legislative-mandated update of Texas coastal erosion rates and subsidence monitoring near several large sinkholes in west Texas. Major activities fully or partly supported by STARR Hazards include:

- An airborne lidar survey of the entire Texas Gulf shoreline beach and dune system conducted between April and June 2019. Lidar and imagery acquired during this effort were used to update historical movement rates for the Texas Gulf shoreline and to assess sand volume stored in the beach and dune system that serves as the natural defense for storm surge accompanying tropical cyclone passage. STARR support supplemented state agency-funded efforts to conduct this study. Results are available to the public and emergency responders through an interactive web viewer hosted on the Bureau's web site.

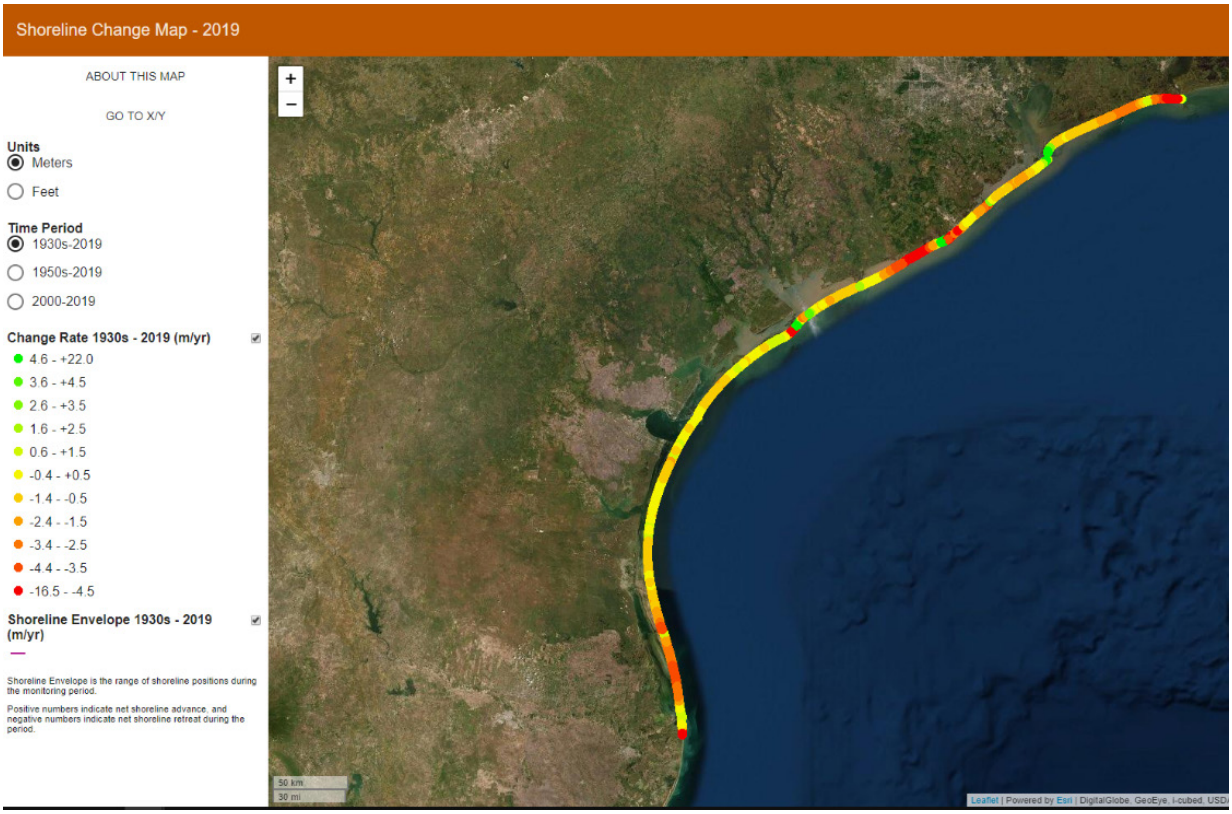

Figure 8. Interactive web viewer depicting historical shoreline erosion rates along the Texas Gulf shoreline. The viewer is available to the public at https://coastal.beg.utexas.edu/shorelinechange2019/.

- Airborne lidar- and ground-based mapping on the Texas coastal plain to assess onshore sand resources that will be needed to support coastal resilience and restoration projects in response to sea-level rise, tropical cyclone impacts, and shoreline erosion. STARR funds are used as required state-sourced matching funds for externally funded projects, allowing us to conduct airborne lidar and ground-based investigations that complement project objectives on the Texas coast. Sand deposits identified during these activities are potential resources for future energy extraction, beach nourishment, and coastal habitat restoration. STARR-supported surveys have identified previously unknown surface faults and enhanced subsidence areas on the Texas coast and were used to complete a geoenvironmental atlas of Powderhorn Ranch, a 17,000+ acre parcel of land recently purchased for the State of Texas for development as a State Park and Wildlife Management Area.

Products

Principal products from STARR-supported activities include presentations at conferences and stakeholder meetings, maps available to the public, interviews, reports, articles, and interactive websites showing historical coastal erosion rates on the Texas Gulf and bay shorelines. For the 2018-2020 biennium, these include:

- Six quadrangle-scale maps showing sand distribution in the Matagorda Bay and Galveston Bay areas. These maps are jointly produced from STATEMAP and STARR Mapping projects and are listed in the STARR Mapping section.

- Seven presentations on effects of Hurricane Harvey, coastal erosion, and sinkholes at the following venues:
    - Hurricane Harvey impacts to the National Coastal Conference in Galveston, the National Academy of Science in Washington, D.C., and the IAMSLIC conference in Port Aransas.
    - Coastal erosion hazards to the National Coastal Conference in Galveston and the General Land Office.
    - Coastal mapping and sand resources to the multiagency Texas Geologic Mapping Advisory Committee, the 2nd Annual Texas Coastal Habitat Mapping Workgroup meeting, the Geologic Mapping Forum, and the Near Surface Geoscience conference, the Gulf Coast Association of Geological Societies, Corpus Christi, Texas, and the Symposium on the Application of Geophysics to Engineering and Environmental Problems in Denver, Colorado.
    - Wink sinkholes to the Geological Society of America in Phoenix, Arizona and Earth Science Week Career Day, Austin, Texas.

- Twelve reports, articles, and abstracts on coastal resources and geologic hazards:
    - Three articles on coastal erosion monitoring, mapping sand deposits on the Texas coastal plain, and sinkhole hazards.
    - Four contract reports to state agencies or the U.S. Geological Survey on coastal erosion studies, coastal hazards, habitat mapping, and sand resources in the Matagorda Bay area.
    - Five conference abstracts on Hurricane Harvey impacts, coastal erosion monitoring, coastal mapping, and sinkhole hazards.

- An interactive website on coastal erosion hazards:
    - Texas Gulf Shoreline Change Project (https://coastal.beg.utexas.edu/shorelinechange2019/)

Connection to Neutrality and Value to Texas

Coastal hazards, sinkholes, and active faults threaten citizens, infrastructure, and economic development across Texas. Studies of geologic hazards benefit Texans by quantifying the impact of natural disasters, highlighting areas of heightened risk, and assessing risk and magnitude of future events. Knowing the context and distribution of geologic hazards helps maximize effective response when an event (like Hurricane Harvey) does occur and minimize its impact through better planning and avoidance of high-risk areas. STARR hazards funds supplement industry sources of funds that are being used to conduct sinkhole hazard studies in West Texas, and numerous State and Federal grants (GLO and National Oceanic and Atmospheric Administration primarily) that support coastal erosion studies on the Texas coast.

Sand resources on the Texas coastal plain will become an increasingly valuable commodity as offshore and dredged-channel sources are consumed in current and planned coastal restoration projects intended to offset chronic coastal erosion and land loss. STARR Hazards funds help supplement existing projects, allowing sand-resource assessments to be conducted in association with other funded coastal projects, leveraging both STARR and project funds.

STARR Endangered Species

Overview and Goals of Project

The projects investigated the status of the habitat of some aquatic endangered species in Texas focusing on the Devils River, often considered "the Most Pristine River in Texas," and on Balmorhea springs, "the Crown Jewel of West Texas." The Devils River shores are mostly privately-owned, and the Balmorhea San Solomon Spring is located in the Balmorhea State Park (Texas Parks & Wildlife Department - TPWD). Both projects used STARR as a small complement to independent funding (U.S. Fish and Wildlife Service and private company, respectively). The Devils River project consisted in inventorying water depth (water bathymetry) along a 50-mile stretch of the river using a LIDAR imagery locally aided by surface-based technologies such as ground-penetrating radar (GPR) (Fig. 9), whereas the Balmorhea San Solomon Spring project was focused in understanding the decadal decrease in spring flow. The goal of both projects was to document whether variations and potential trends in water abundance, as environmental threats to federally protected species, could trigger detrimental costly consequences.

Description of Results and Findings

The Devils River study showed that airborne LIDAR imagery is an effective remote-sensing technology that can collect most necessary information efficiently in complex settings with some caveats (e.g., thick aquatic vegetation negatively influences the LIDAR system), provided that results are calibrated by a few selected ground observations. Water depth results and other parameters can be matched with known preferred habitats of target species, whose locations can then inventoried and protected as needed. The still on-going Balmorhea spring study is also focused on data acquisition, in particular, by drilling monitoring wells to assess impact of pumping and other activities, as well as natural mechanisms, on the spring flow rate. The project also supported the instrumentation of several ephemeral streams and springs in the nearby Davis Mountains, as their flows contribute to the Balmorhea spring flow.

Products and Outcomes

Saylam, K., Averett, A.R., Costard, L., Wolaver, B.D., and Robertson, S., 2020, Multi-Sensor Approach to Improve Bathymetric Lidar Mapping of Semi-Arid Groundwater-Dependent Streams: Devils River, Texas: Remote Sensing, v.12, no.2491, 24 p., http://doi.org/10.3390/rs12152491.

Connection to Neutrality and Value to Texas

Funds have been used to complement the main funding of the projects (approximately $36,000 and $26,000, respectively, for the biennium). The complements were relatively small (13% and 2% of total budget, respectively) but instrumental in receiving the other funds as they show

strong commitment from the State Geological Survey (BEG). Studies of potential threats of an environmental nature benefit the State by allowing stakeholders to be proactive and minimize their impact before they become a serious ecological or financial risk. STARR funds supplemented such studies in support of the good health of Texas water bodies.

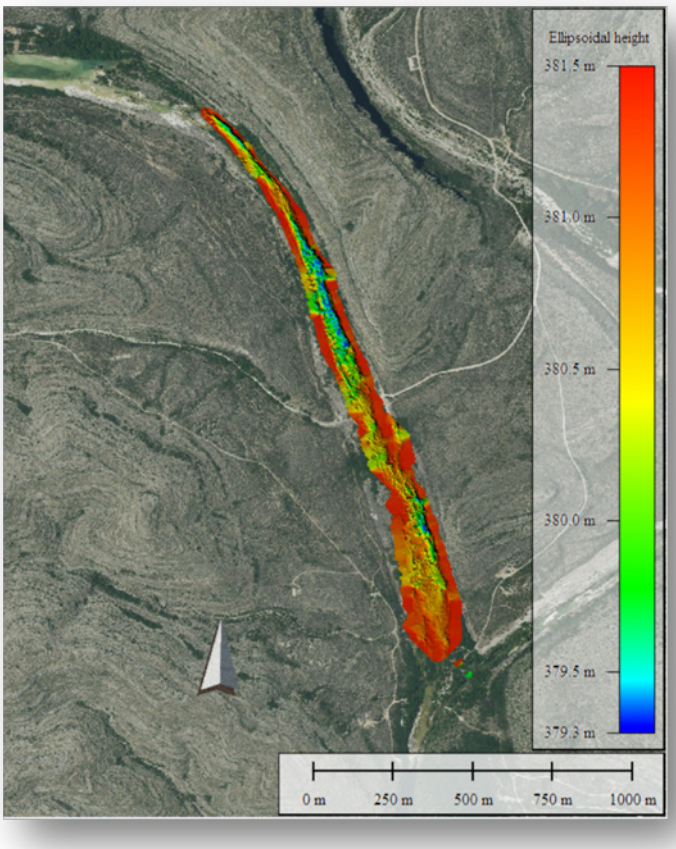

Figure 9. Representative results of LIDAR-derived imagery, augmented using ground-penetrating radar (GPR).

Mapping and Mineral/Earth Resources of Texas

Overview and Goals of Project

This project produces geologic maps and related products to support the development and management of Texas' natural resources. The diverse geologic formations of Texas provide many industrial rocks and minerals used by Texas' industries and inhabitants. Minerals are produced across Texas and are mostly related to construction and industrial activities (Fig. 10). Demand for earth materials that are used in the construction, chemical, and hydrocarbon exploration and production industries increases with population and economic growth. Geologic maps are a basic data set used by professionals to aid in exploration and evaluation of earth resources. Maps and related materials foster economic development and support the ability to locate and develop mineral and water resources, to identify and plan for potential hazards, to assess change in sensitive environments, and to properly plan and permit major construction projects. This project supports the development and management of Texas' mineral/earth resources by providing basic geologic information, such as geologic maps (Fig. 11), to the public.

The STARR Geologic Mapping and Mineral/Earth Resources of Texas project complements the STARR Hazards Mapping and Response project and Texas STATEMAP project, which is partly supported by the National Geologic Mapping Cooperative Program administered by the U.S. Geological Survey. Possible mapping areas in Texas are prioritized by an advisory committee composed of representatives from the Texas Water Development Board, Texas Natural Resources Information System, Railroad Commission of Texas, Texas General Land Office, and Texas Parks and Wildlife Department, with coordination from the Bureau of Economic Geology. Geologic mapping and resource assessment activities during the September 2018-August 2020 biennium were conducted on the upper and middle Texas Gulf of Mexico coastal plain, in south-central Texas, in the central Texas urban corridor, and in the mineral district of central Texas.

Description of Results and Findings

Two geologic maps produced for areas in south-central Texas with geologic units of potential sand and aggregate resources that are vitally important to the cement, construction, and oil and gas industries. Joint mapping for Texas STATEMAP Program and STARR.

One geologic map produced for the central Texas area with geologic units of potential industrial or hydraulic fracturing sand resources and limestone aggregate resources. Joint mapping for Texas STATEMAP Program and STARR.

Four geologic maps produced for middle Texas Gulf of Mexico Coast area of sensitive coastal environments, potential sand resources, and coastal land loss. Joint mapping for Texas STATEMAP Program and STARR.

Two geologic maps produced for upper Texas Gulf of Mexico Coast area of sensitive coastal environments, potential sand resources, and coastal land loss. Joint mapping for Texas STATEMAP Program and STARR.

Three geologic maps for the central Texas area produced for geologic data applicable to earth and water resources and engineering projects of population corridors. Joint mapping for Texas STATEMAP Program and STARR.

Continued to develop and update a mineral resources map of Texas through the BEG website https://coastal.beg.utexas.edu/txmineralresources/#!/

Continued to develop and update a Texas aggregate resource map for type, characterization, and quality of road and construction materials through the BEG website that can be used by industry professionals to explore regional aggregate material access: http://coastal.beg.utexas.edu/txdot_aggregate/#/

Promoted industry connections and fostered relationships with organizations and agencies that maintain resource-related data, as well as individual company operations, including U.S. Geological Survey, Department of Energy, Department of Interior, Texas Mining and Reclamation Association, Texas Aggregate and Concrete Association, Texas Cement Association, Texas Water Development Board, Texas Department of Transportation, Texas Railroad Commission, Texas Commission on Environmental Quality, and Texas Workforce Commission.

Responded to more than 100 public inquiries concerning mineral occurrences, deposits, data and available publications, many from companies and consultants looking for resource location information. Common inquiry topics included rocks and minerals, regional and local geology, engineering geology, geologic hazards, and resource-specific questions concerning uranium, sand and gravel, hydraulic fracturing sand and high quality industrial sands, natural clay materials, rare earth elements, silver, molybdenum, and vanadium resources, zeolite resources, gypsum, sulfur and graphite deposits, crushed limestone, trap-rock and other aggregate resources, heavy sands with possible titanium, zirconium, and niobium associations, and lithium and potash resources.

Presented results of mapping and mineral-resources research at regional and national geological and geophysical meetings, including the Geological Society of America and the Symposium on the Application of Geophysics to Engineering and Environmental Problems, and at Industry Day hosted by BEG.

List of Products and References

Principal STARR mapping- and minerals-focused products completed during the 2018-2020 biennium include 5 articles and reports, 11 geologic maps, 2 web resource pages, and numerous public presentations at conferences, state and federal government agencies, and other public venues.

Caudle, T. L., and Paine, J. G., 2019, Geologic map of the Flake quadrangle, Texas Gulf of Mexico Coast: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map No. 238, 1:24,000.

Elliott, B.A., 2018, Petrogenesis of heavy rare earth element enriched rhyolite: Source and magmatic evolution of the Round Top laccolith, Trans-Pecos, Texas. Minerals 8 (10), 423, https://doi.org/10.3390/min8100423

Elliott, B.A., 2018, The West Texas Sand Rush, Fifty-Fourth Forum on the Geology of Industrial Minerals, Austin, TX, Bureau of Economic Geology, the University of Texas at Austin.

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Elliott, B. A., 2020, Geologic map of the Katemcy quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map No. 244, 1:24,000.

Kyle, J. R., 2018, Industrial Minerals of Texas: The University of Texas at Austin, Bureau of Economic Geology, State Map Series, SM0011.

Kyle, J. R., Elliott, B. A., 2019, Past, present, and future of Texas industrial minerals: Mining, Metallurgy & Exploration, v. 36, p. 475–486. doi.org/10.1007/s42461-019-0050-1.

Paine, J. G., Caudle, T., Costard, L., Elliott, B. A., and Woodruff, C. M., Jr., 2020, Texas STATEMAP program summary, FY19 (2019-2020): Bureau of Economic Geology, The University of Texas at Austin, Final Technical Report prepared for U.S. Geological Survey, under contract no. G19AC00225, 19 p.

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Paine, J. G., and Costard, L., 2019, Geologic map of the Placedo quadrangle, Texas Gulf of Mexico Coast: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map No. 240, 1:24,000.

Paine, J. G., and Costard, L., 2019, Geologic map of the Port Lavaca West quadrangle, Texas Gulf of Mexico Coast: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map No. 239, 1:24,000.

Paine, J. G., and Costard, L., 2020, Geologic map of the Bloomington quadrangle, Texas Gulf of Mexico Coast, Sheet 1: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map No. 246, 1:24,000.

Paine, J. G., and Costard, L., 2020, Geologic map of the Olivia and part of the Keller Bay quadrangle, Texas Gulf of Mexico Coast, Sheet 1: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map No. 247, 1:24,000.

Woodruff, C. M., Jr., and Collins, E. W., 2019, Geologic map of the lower Lake Travis and Lake Austin vicinity, Texas: The University of Texas at Austin, Bureau of Economic Geology, Miscellaneous Map No. 53, 1:50,000.

Woodruff, C. M., Jr., and Costard, Lucie, 2020, Geologic map of the Taylor quadrangle, Blanco County, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map No. 243, 1:24,000.

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Connection to Neutrality and Value to Texas

STARR Mapping and Earth/Mineral Resources of Texas work integrates much of its effort with the ongoing BEG Texas STATEMAP program, an established, ongoing geologic mapping program that began in 1992. Integrating work for this program allows for state funds to be matched with federal funds, increasing the productivity (and budgets) of the programs. The Texas STATEMAP program also complements ongoing studies of geologic hazards affecting Texas and studies of the status and trends of wetland environments and aquatic habitats.

STARR funds accounted for most of the required cost share for federal funds awarded in the amount of $898,845 for the STATEMAP and related federally funded programs in the 2018, 2019, and 2020 fiscal years.

STARR funds accounted for most of the required cost share for externally sponsored project funds ($65,768) from mining industry interests in developing an inventory for oilfield brine chemistry and its potential to produce critical mineral resources from August 2017-August 2019 and for the entire $49,538 state match required to obtain an equal amount of federal support to identify critical minerals in Texas.

Geologic maps and related charts, diagrams, and texts, are a type of product that has been documented to have great economic and societal value (Bhagwat and Ipe, 2000; GSA Geology & Public Policy Committee, 2012). For example, one analysis calculated the value of the geologic maps to be 25 to 30 times the cost of map preparation. Geologic maps and their related materials foster economic development and support the ability to locate and develop mineral and water resources, to identify and plan for potential hazards, to assess changes in sensitive coastal environments, and to properly plan and permit major construction projects.

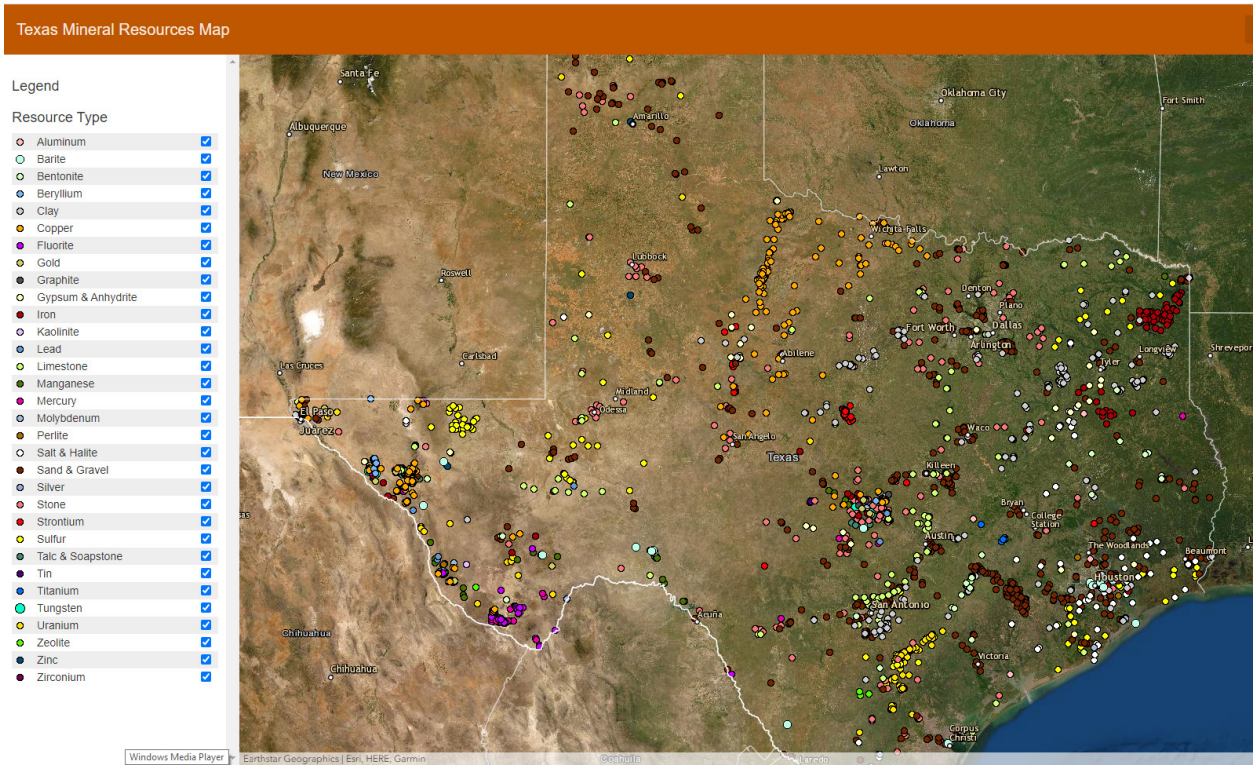

Figure 10. Texas Mineral Resources Map viewer showing distribution of mineral resources in Texas. The viewer is available to the public at https://coastal.beg.utexas.edu/txmineralresources/#!/

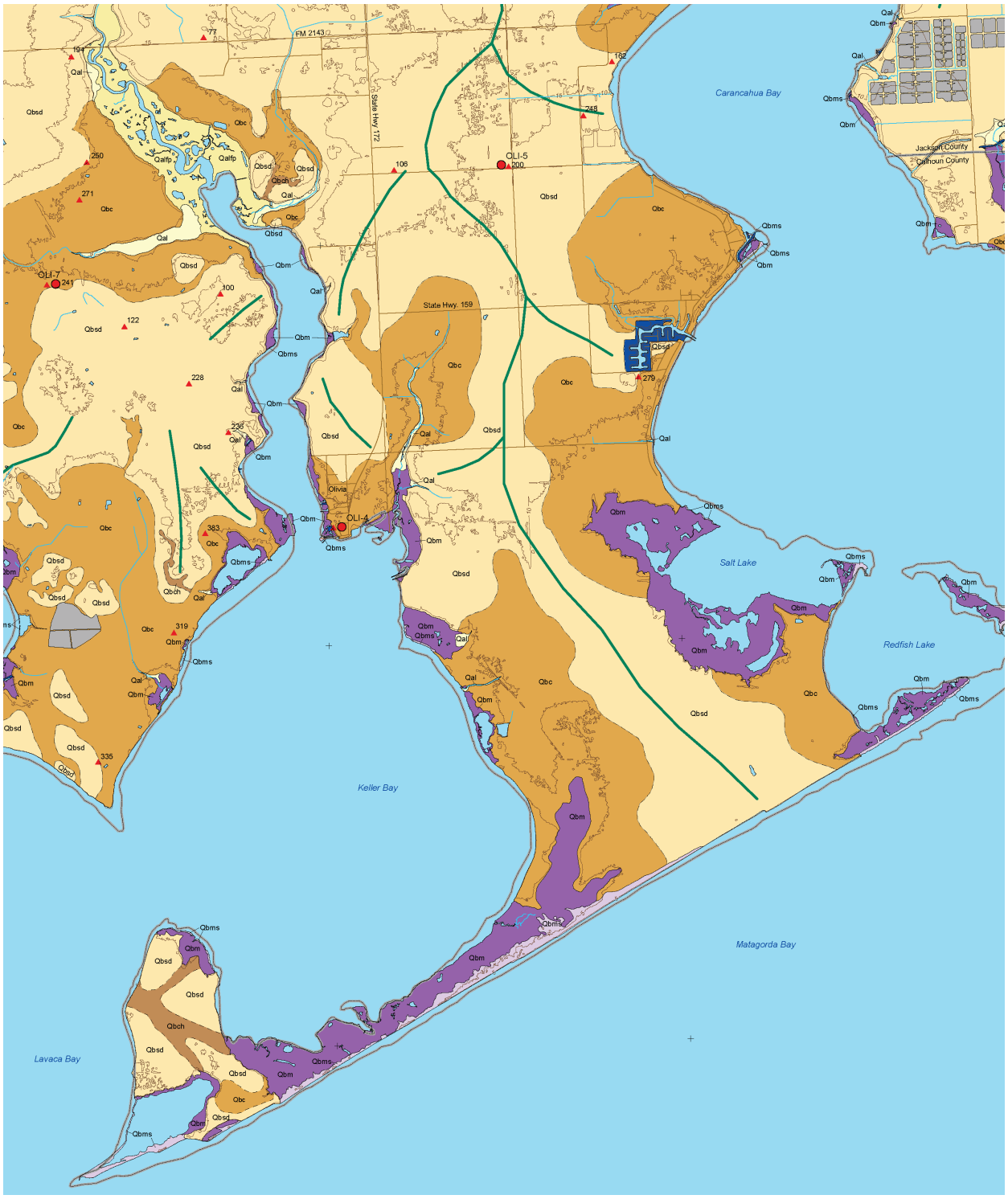

Figure 11. A portion of the geologic map of the Olivia quadrangle on Matagorda Bay showing distribution of sandy former channel deposits (Paine, 2020).

References

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Paine, J. G., 2020, Geologic map of the Olivia and part of the Keller Bay quadrangles, Texas Gulf of Mexico coast: The University of Texas at Austin, Bureau of Economic Geology, no. 247, 1:24,000, 2 sh.