Consortium Advancing Technology for Assessment of Lost Oil & Gas Wells.

IOGCC Undocumented Orphan Wells Program Update

BERKELEY LAB · Los Alamos National Laboratory · Lawrence Livermore National Laboratory · National Energy Technology Laboratory · Sandia National Laboratories

Bi-Partisan Infrastructure Legislation

Relevant Appropriations Language

Section H2 (a, b)
Conduct research and development activities in cooperation with the **Interstate Oil and Gas Compact Commission** to assist the Federal land management agencies, **States**, and Indian Tribes in--
(A) identifying and characterizing undocumented orphaned wells; and
(B) mitigating the environmental risks of undocumented orphaned wells;

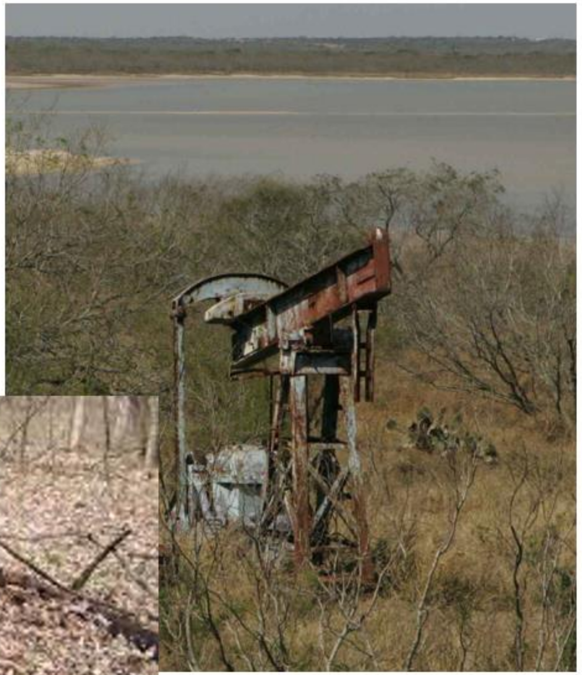
Program Budget

DOE's Undocumented Orphaned Well Program will be executed over **5 years with $30M** in appropriated budget.

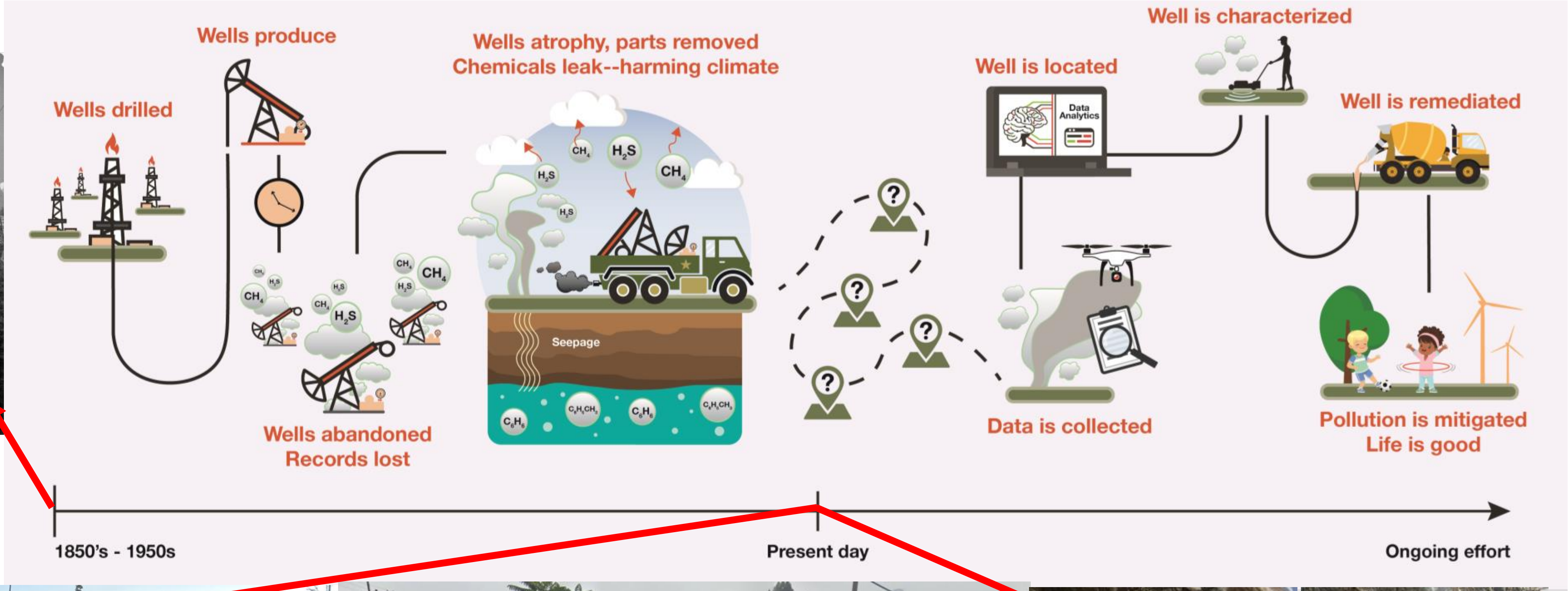
FY2023 Appropriations

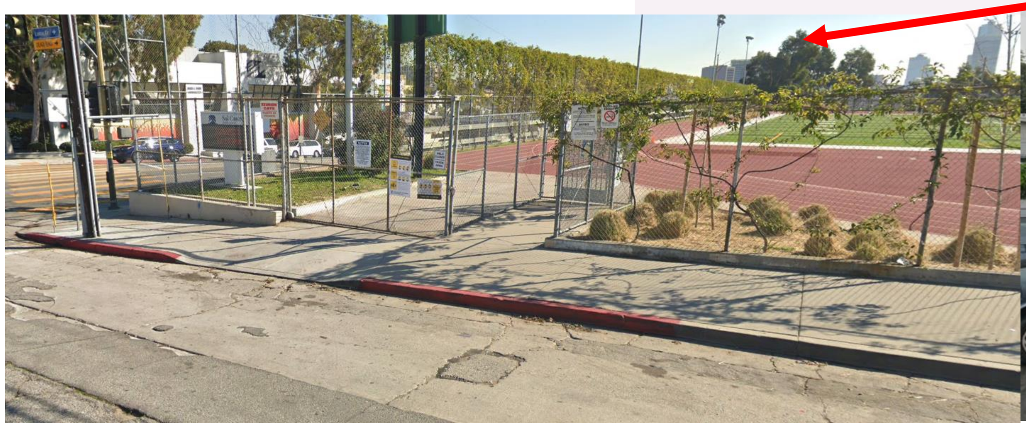
Up to $10 million to be spend on identification and characterization of undocumented orphaned wells.

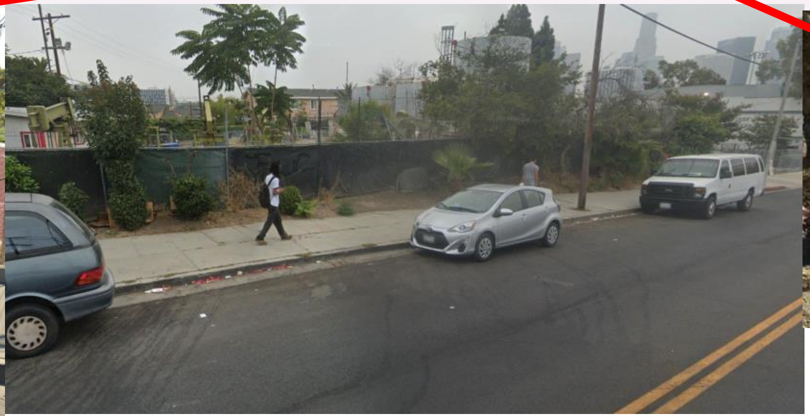
IOGCC 2021 estimate of undocumented orphaned wells is between **310,000** and **800,000**.



Orphan wells are hard to find and impact peoples' lives

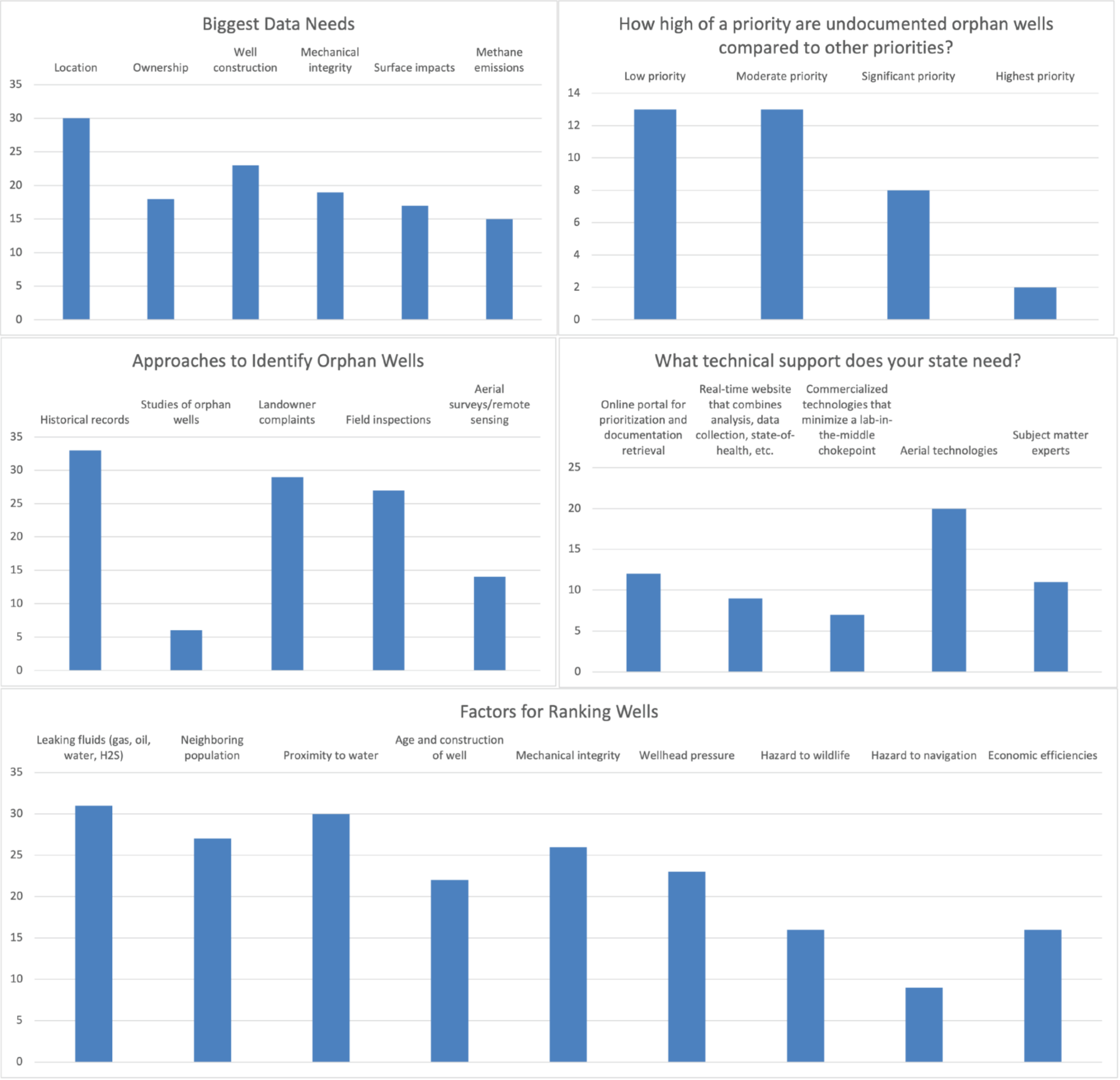






State Survey Results

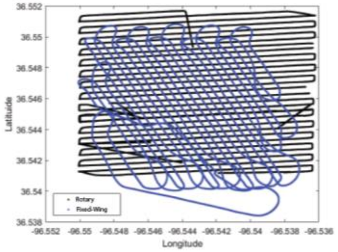
- We surveyed the states to gather input on priorities and current practices
- This input is vital to setting our research goals
- We welcome ongoing feedback and understand that things will change as we all get more experience with this
    - Please reach out to us!

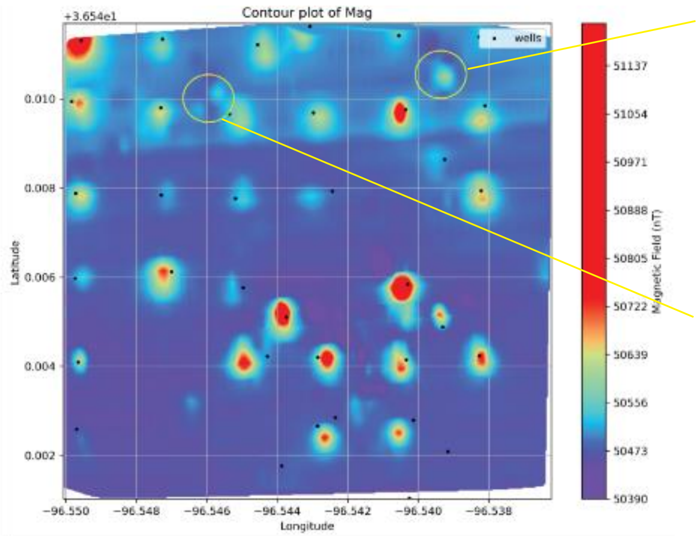


Three stages of orphan well remediation

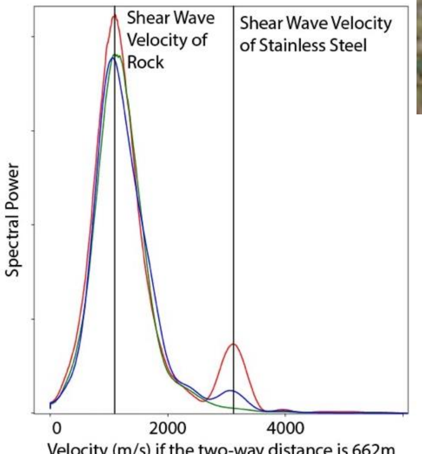
Before going into the field

Finding wells with field work

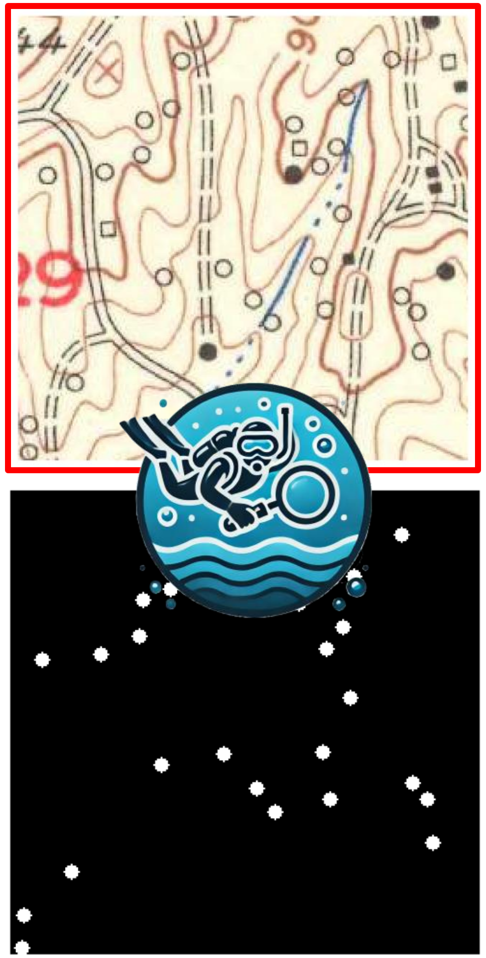




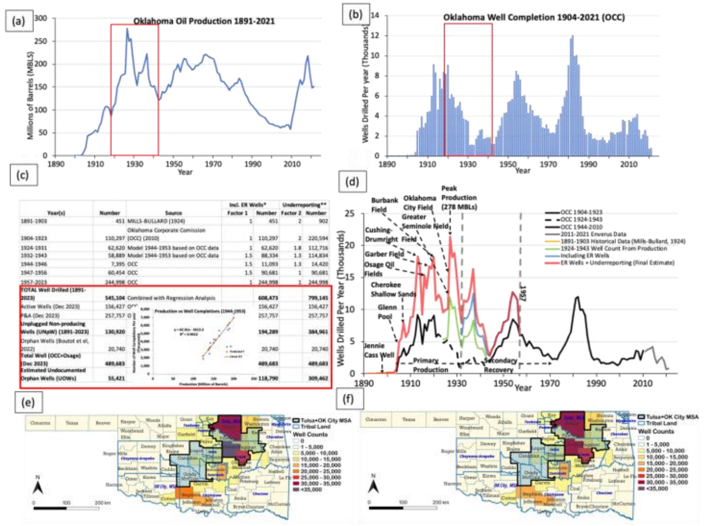
After finding a well



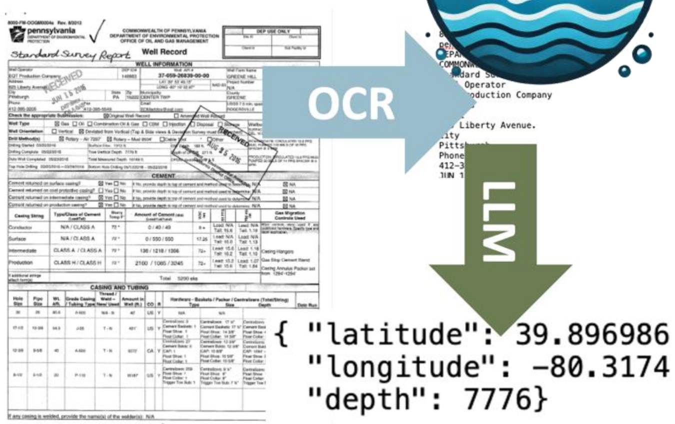
Preparation before fieldwork pays off



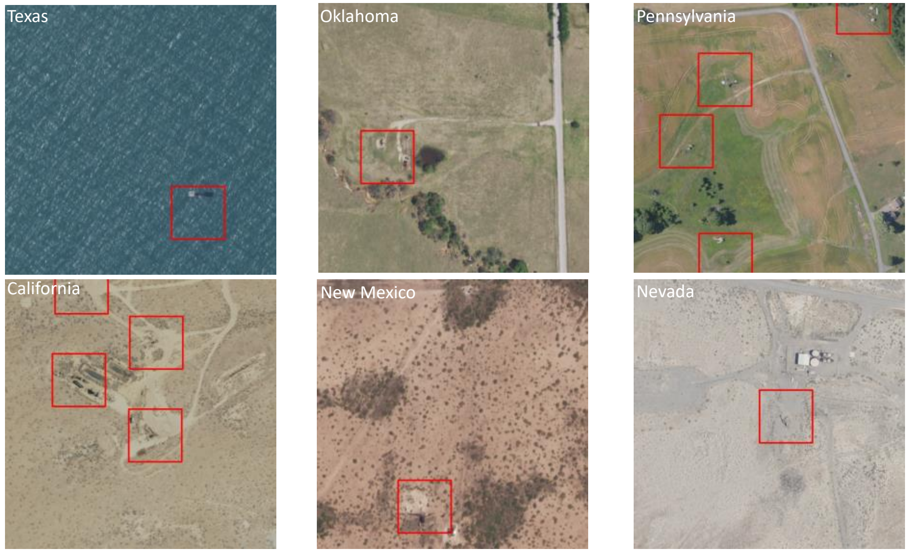
Pulling well locations off of historical maps



Studying historical production to produce county-level estimates of unplugged nonproducing wells



Extracting well information from historical records with AI

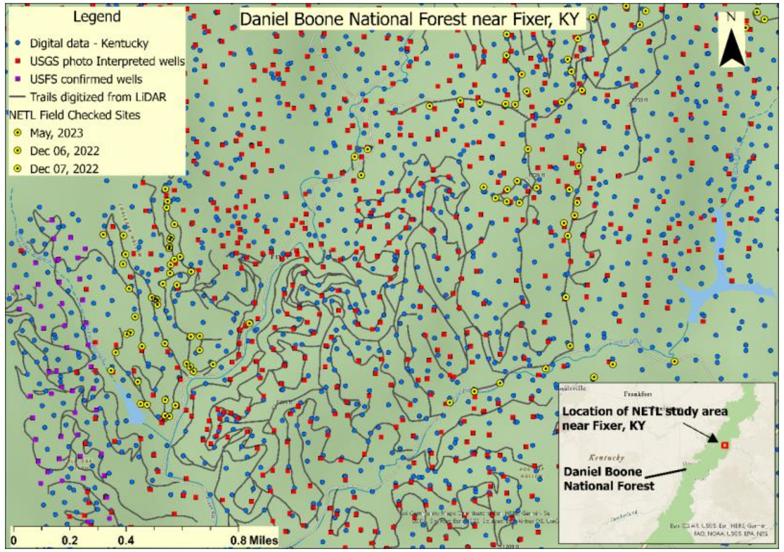


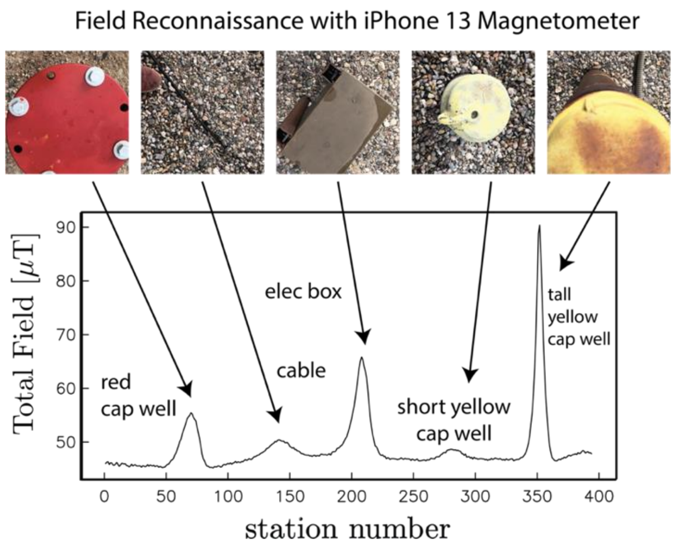
Locate wells with aerial imagery

No silver bullet for finding wells in the field

Had success with a fixed wing drone in high winds and rain when a rotary drone failed

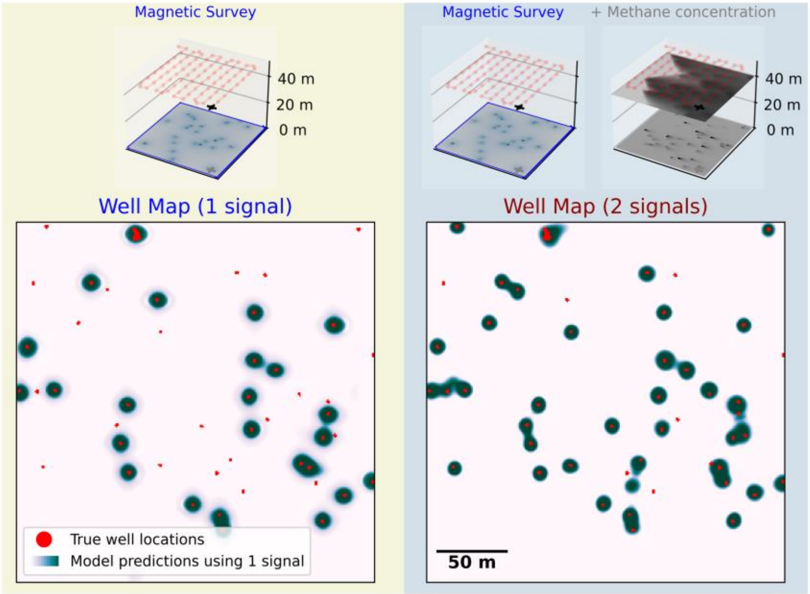
Different types of data often indicate different well locations





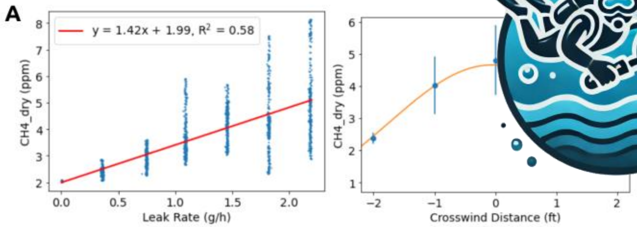
Citizen scientists can help using sensors on smartphones

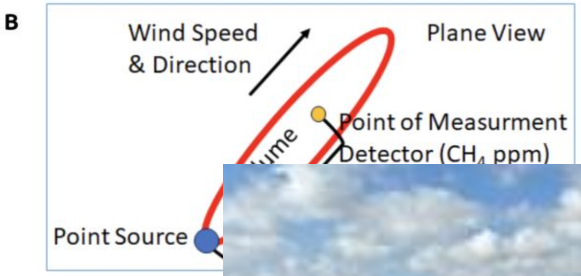
Combining multiple sensors helps AI find wells better than a single sensor

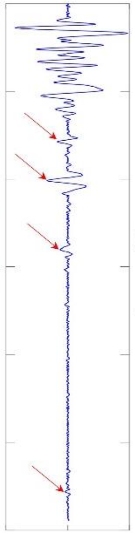


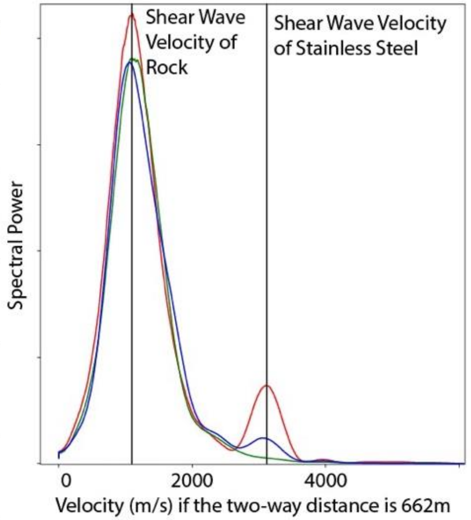
Characterization & plugging after finding a well

We are developing cost-effective methods and best practices for quantifying emissions from orphan wells





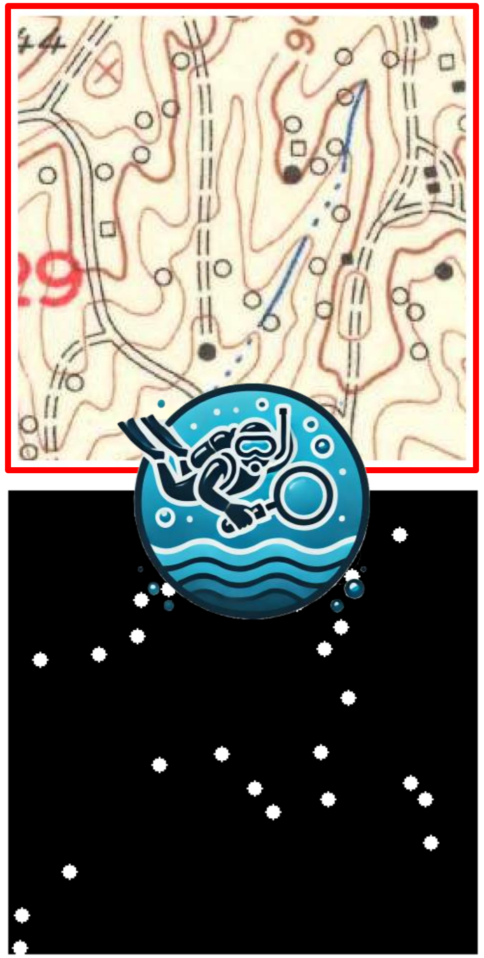




Developing innovative methods for characterization without downhole instruments

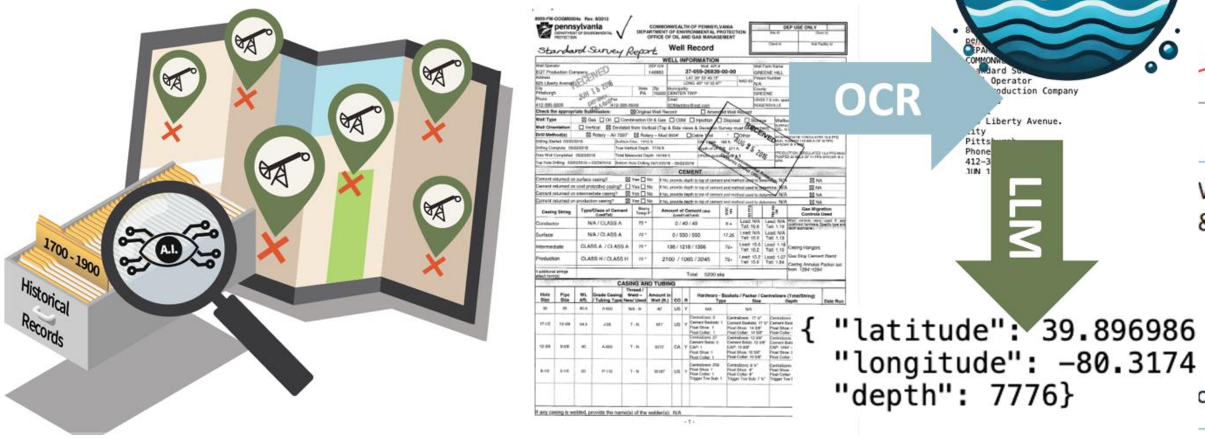
The ultimate goal, of course, is to properly plug & abandon the wells to mitigate their environmental impacts

Transitioning into the deep dives

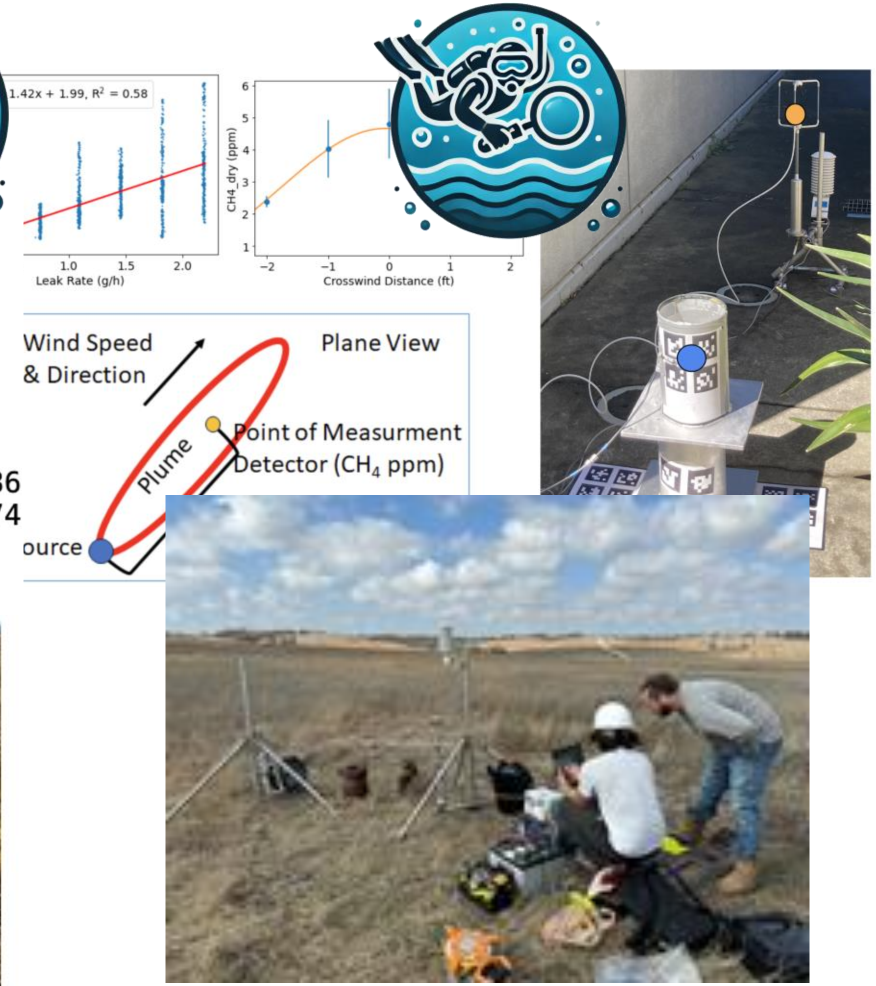


Fabio Ciulla

Greg Lackey



Christine Sweeney



Sebastien Biraud

Undocumented Orphaned Wells Identification from Historical Topographic Maps

Fabio Ciulla
fciulla@lbl.gov

A Deep Learning Based Framework to Identify Undocumented Orphaned Oil and Gas Wells from Historical Maps: a Case Study for California and Oklahoma

in review

Fabio Ciulla,* Andre Santos, Preston Jordan, Timothy Kneafsey, Sebastien C. Biraud, and Charuleka Varadharajan*

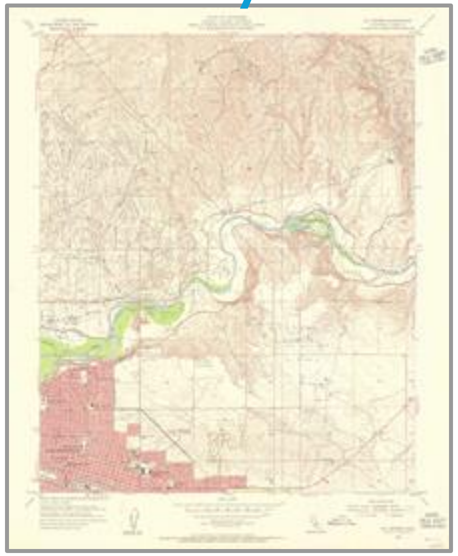
Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

The Dataset

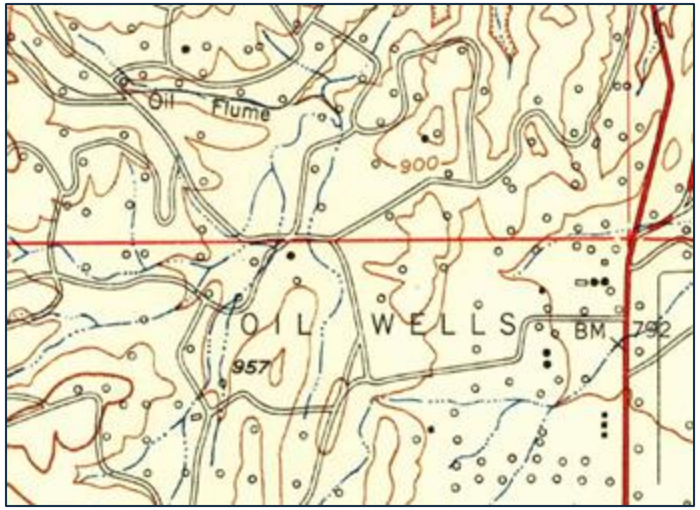
Method for **automated identification** and **accurate location** of UOWs at **regional to continental scales**

Historical Topographic Maps Collection (HTMC): set of 190,000 **georeferenced** raster maps covering the **entire US** published by the USGS **since 1884**.

Quadrangles (1947 - 1992) focus on **consistency** of **colors** and **symbols**



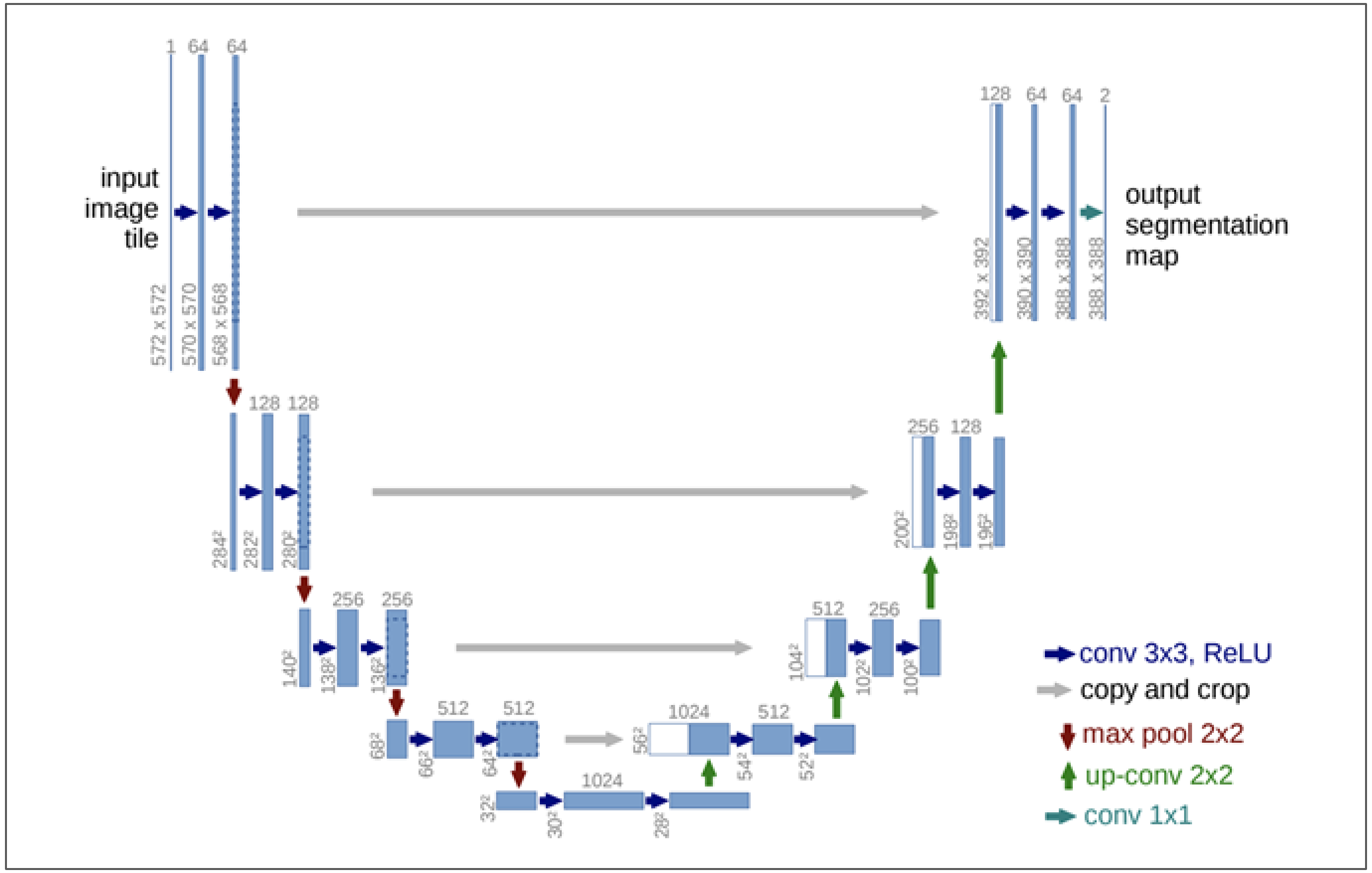
Oil and gas wells consistently represented as **hollow black circles**



Challenge: symbols must be detected!

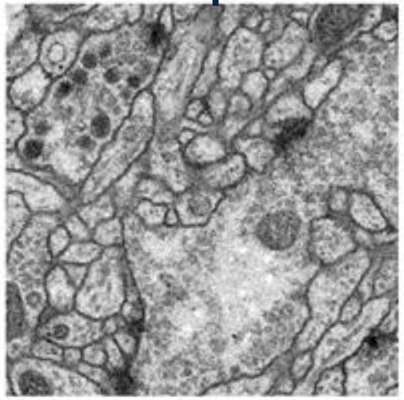
AI for Computer Vision

Convolutional neural network algorithm for image segmentation

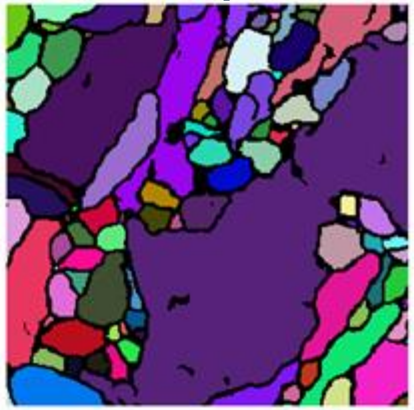


Originally developed to segment biomedical images

input



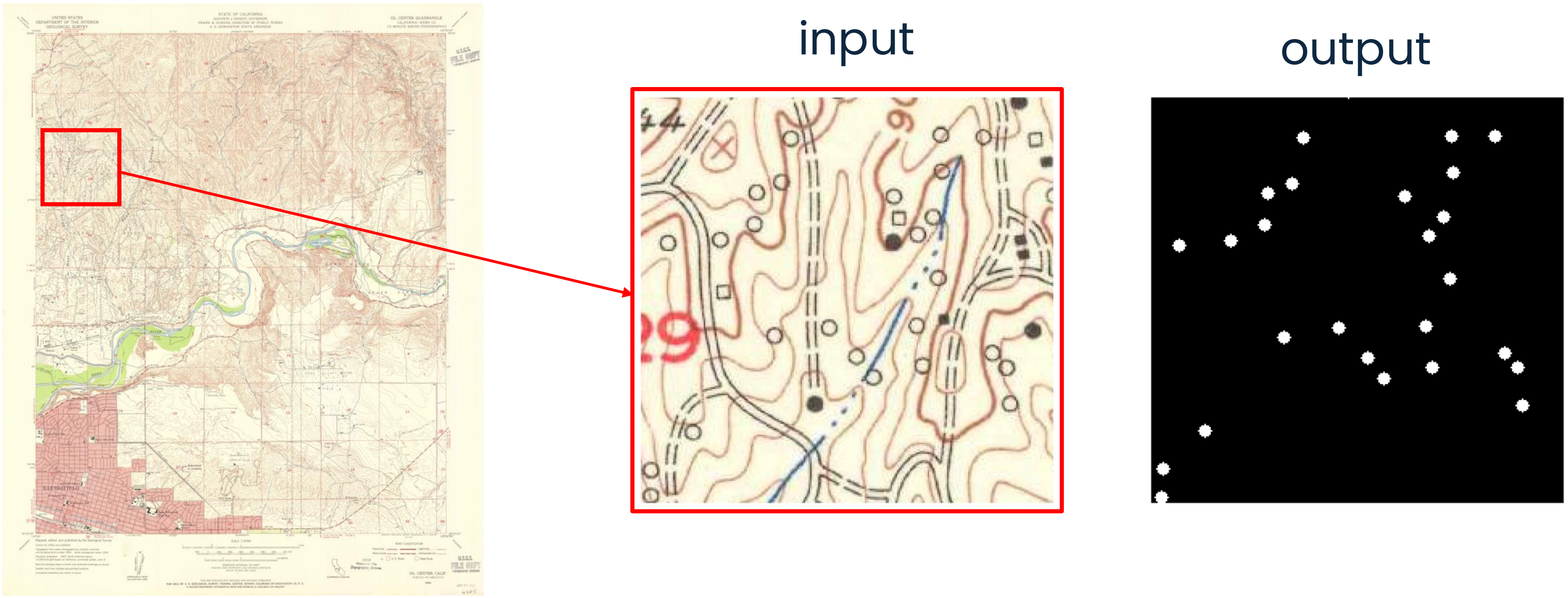
output



Ronnerberger et al., (2015) U-Net: Convolutional Networks for Biomedical Image Segmentation. arXiv

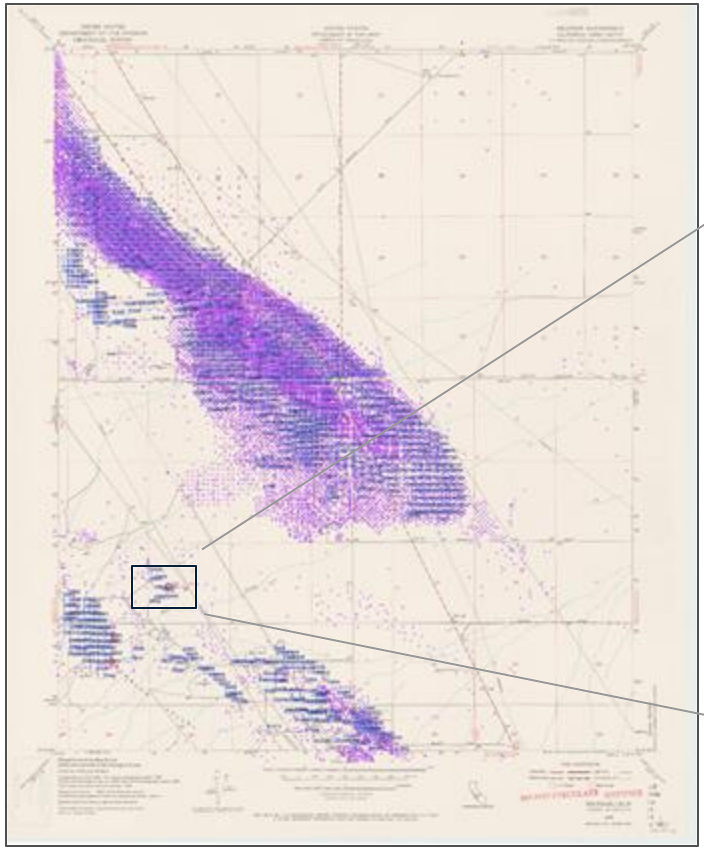
AI on topographic maps

11,046 well symbols labeled from **79 different maps**

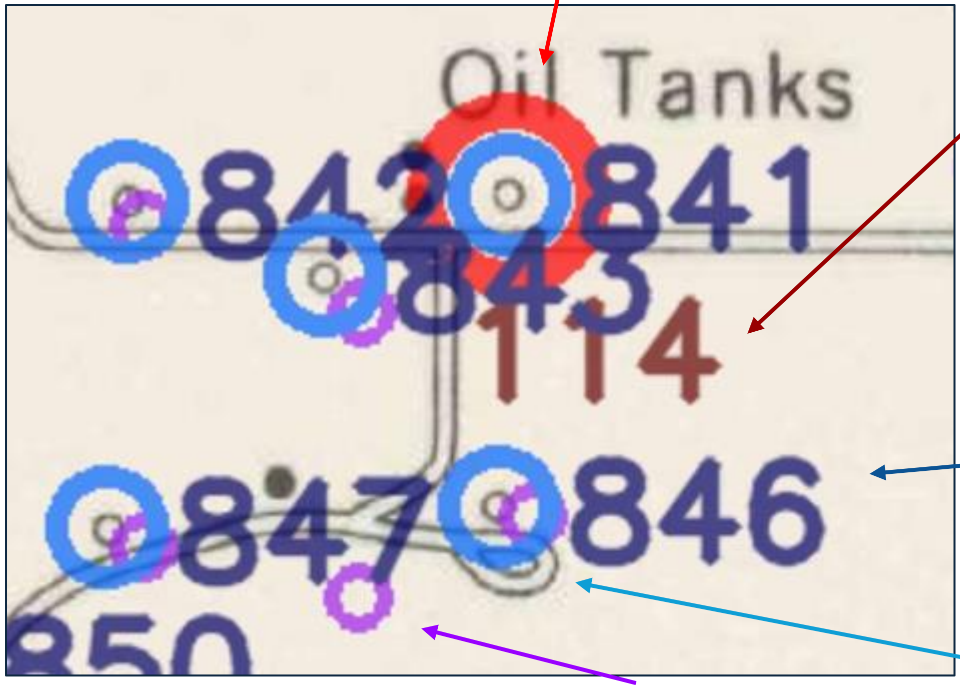


Method - Inference

Each map gets **enriched** with geographical information of the detected wells



Detected wells **further than 100m** from the closest documented well are flagged as **potential UOWs**



distance to nearest documented well

unique ID

detected well

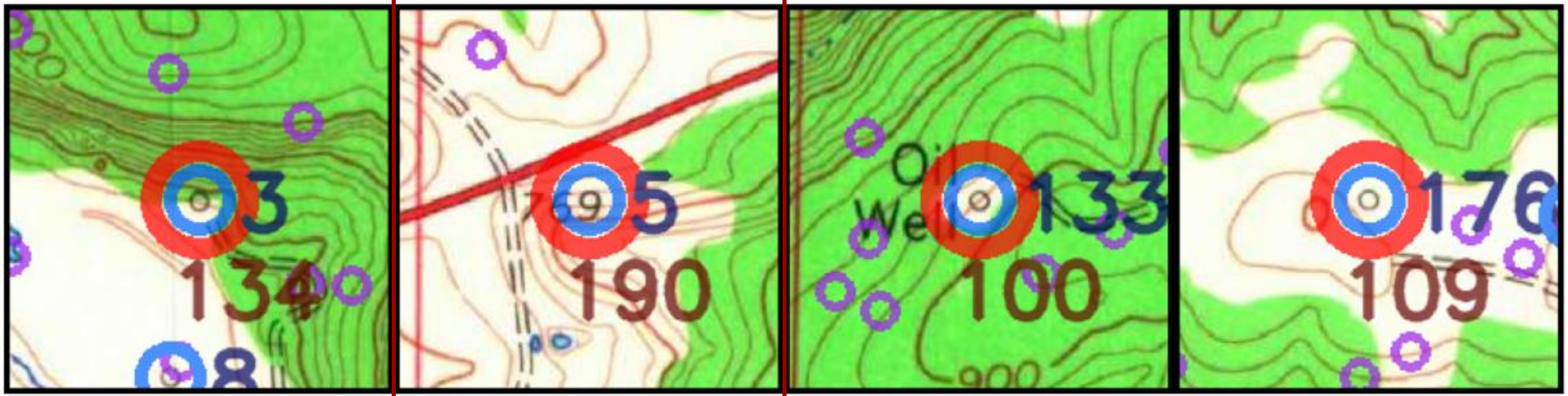
documented well

Method – Vetting Results

Script to isolate potential UOWs for **visual evaluation**

Vetting time: about 1,000 potential UOWs per hour

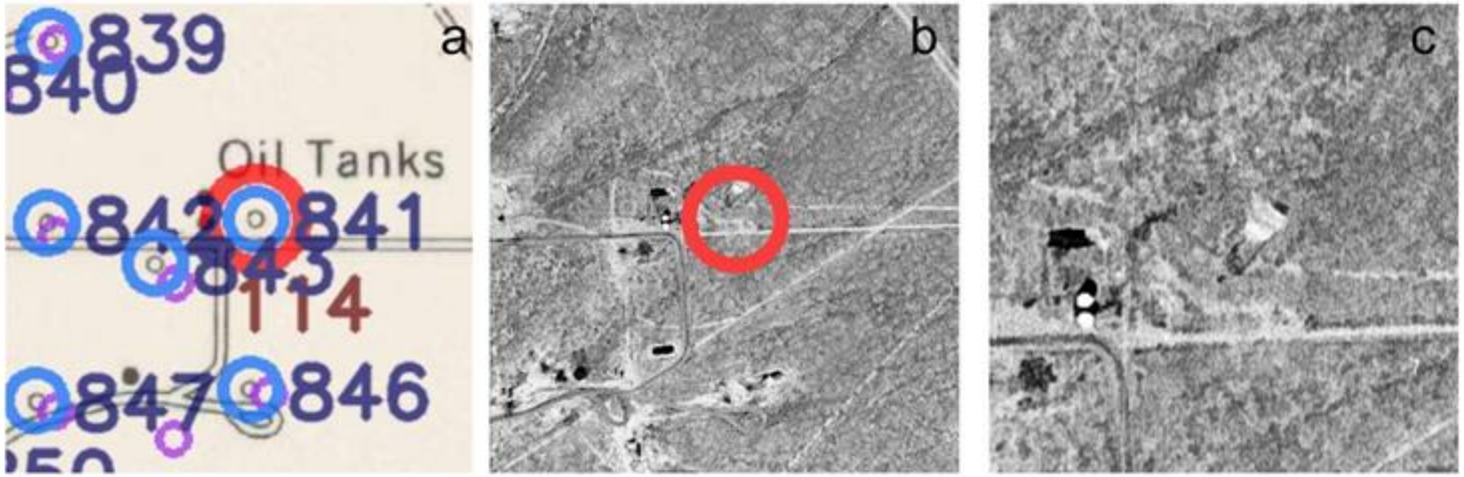
Wrong detection



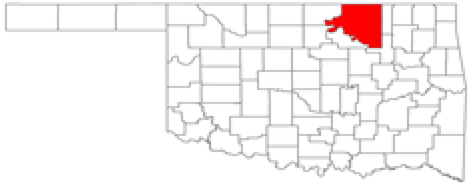
Method – Remote Validation

Evidence from **current satellite imagery** (Google Maps)

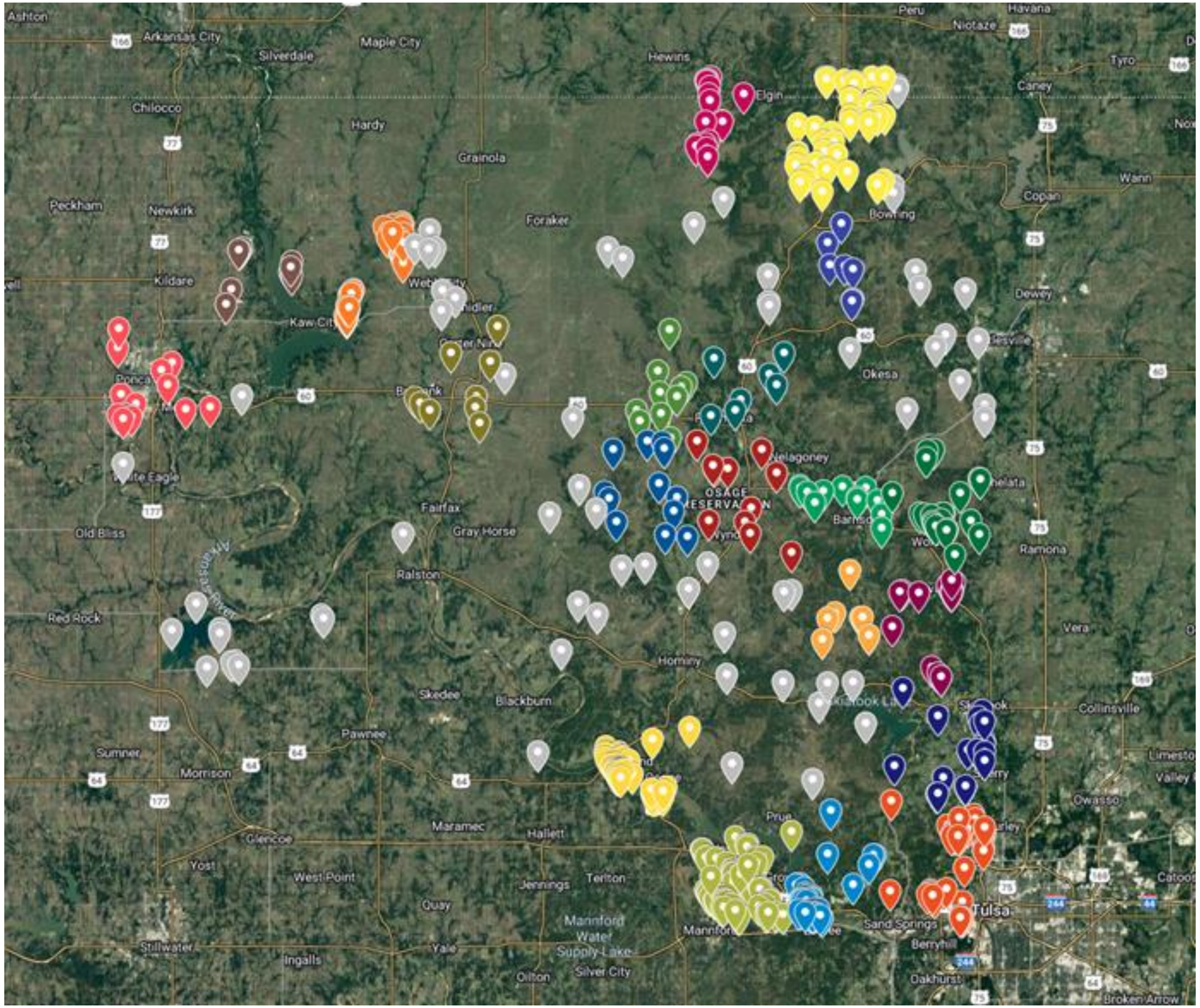
Historical Aerial photos checked when no structure visible as of today



Results – Osage County

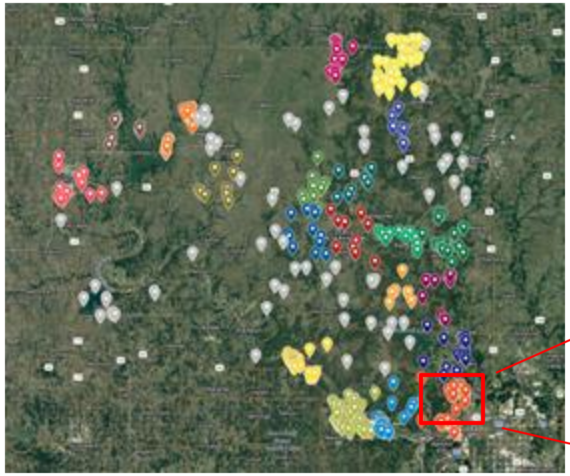


Surface (km²)	5,970
Potential UOWs	**261**
UOWs per 1,000 km²	43.7
Ratio UOWs to documented wells	5.9×10^{-3}



credits: Google Maps

Results – Osage County

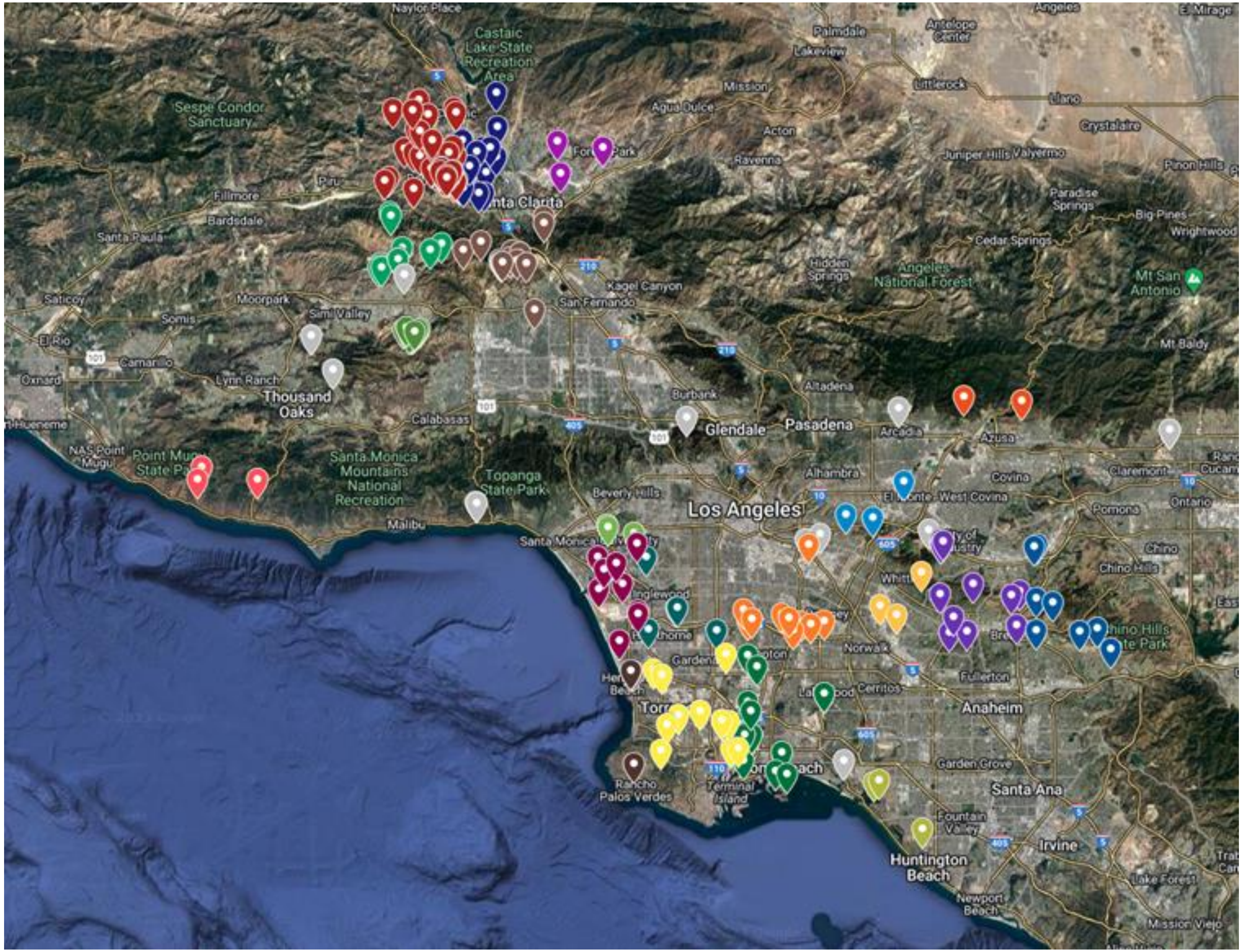


Potential UOWs visible from **current satellite imagery**

Documented wells in blue in this image for reference

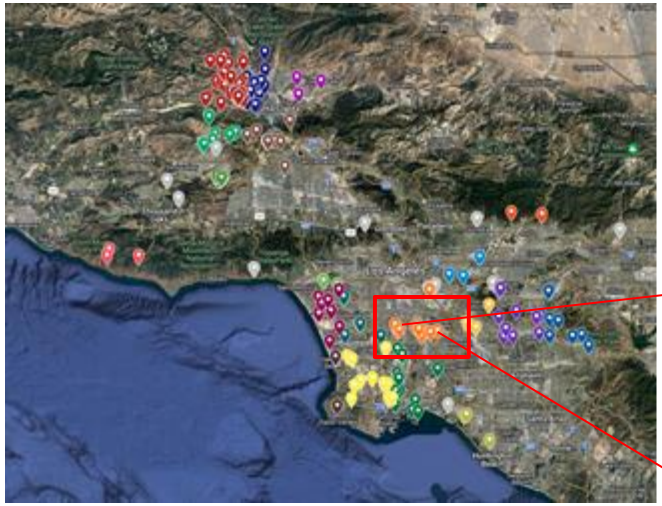
Results – Los Angeles County

Surface (km^2)	12,310
Potential UOWs	**181**
UOWs per 1,000 km^2	14.7
Ratio UOWs to documented wells	$7.9x10^{-3}$



credits: Google Maps

Results – Los Angeles County



Proximity to **hospitals**, **schools**, **apartment buildings**


California Lagged in Capping Century-old Oil Wells Leaking Under Homes of LA Residents Plagued by Illness and Odors

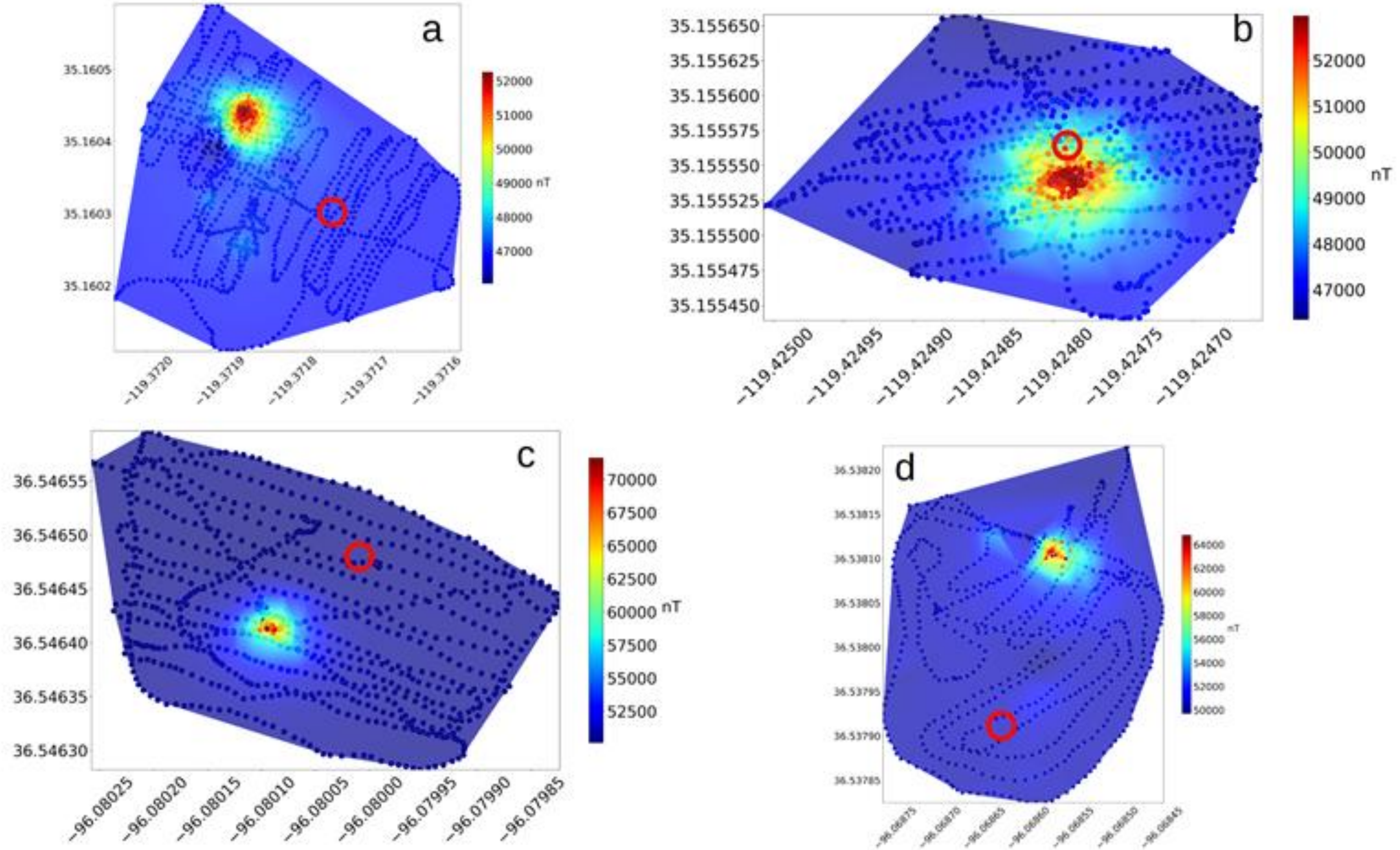
In private residence **backyards**

Results – Field Validation

Magnetic signature is consistent with presence of well.

Average distance from detected locations in maps: **11.7±1.8m**

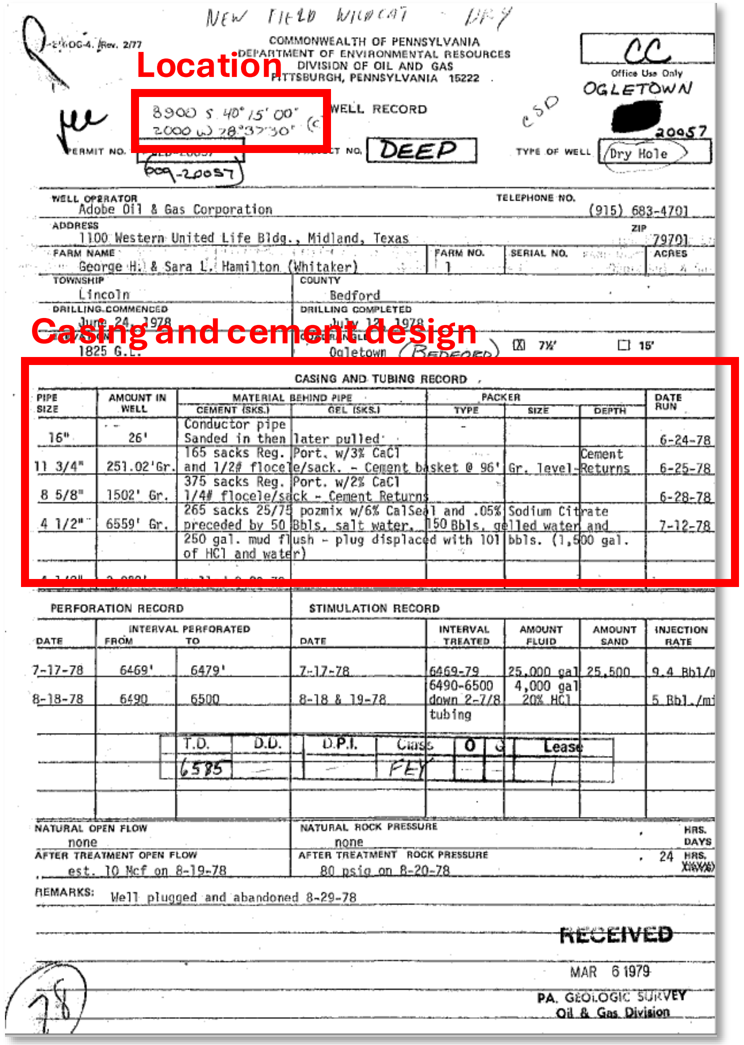
Average distance **consistent with the remote validation** one within the error



Well Data "Trapped" in Records

- Records document well permitting and construction process
- Many records have been scanned but are not in a machine-readable format

Oil & gas regulatory records contain valuable information about wells that remains "trapped" on scanned forms



NEW FIELD WILDCAT - DRY

OG-4. Rev. 2/77

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
DIVISION OF OIL AND GAS
PITTSBURGH, PENNSYLVANIA 15222

WELL RECORD

CC
Office Use Only
OGLETOWN
[redacted] 20057

8900 S 40° 15' 00"
2000 W 78° 37' 30"

PERMIT NO. 009-20057
PROJECT NO. DEEP
TYPE OF WELL: Dry Hole

WELL OPERATOR: Adobe Oil & Gas Corporation
TELEPHONE NO. (915) 683-4701
ADDRESS: 1100 Western United Life Bldg., Midland, Texas
ZIP: 79701
FARM NAME: George H. & Sara L. Hamilton (Whitaker)
FARM NO.: 1
SERIAL NO.:
ACRES:
TOWNSHIP: Lincoln
COUNTY: Bedford
DRILLING COMMENCED: June 24, 1978
DRILLING COMPLETED: July 12, 1978
ELEVATION: 1825 G.L.
QUADRANGLE: Ogletown (BEDFORD) [X] 7½' [ ] 15'

CASING AND TUBING RECORD

PIPE SIZE	AMOUNT IN WELL	MATERIAL BEHIND PIPE: CEMENT (SKS.)	GEL (SKS.)	PACKER: TYPE	SIZE	DEPTH	DATE RUN
16"	26'	Conductor pipe Sanded in then	later pulled	-			6-24-78
11 3/4"	251.02' Gr.	165 sacks Reg. and 1/2# flocele/sack.	Port. w/3% CaCl - Cement basket @ 96'		Gr. level-	Cement Returns	6-25-78
8 5/8"	1502' Gr.	375 sacks Reg. 1/4# flocele/sack	Port. w/2% CaCl - Cement Returns				6-28-78
4 1/2"	6559' Gr.	265 sacks 25/75 preceded by 50 250 gal. mud flush - plug of HCl and water)	pozmix w/6% CalSeal and .05% Sodium Citrate Bbls. salt water. 150 Bbls. gelled water and displaced with 101 bbls. (1,500 gal.				7-12-78

PERFORATION RECORD

DATE	INTERVAL PERFORATED FROM	TO
7-17-78	6469'	6479'
8-18-78	6490	6500

STIMULATION RECORD

DATE	INTERVAL TREATED	AMOUNT FLUID	AMOUNT SAND	INJECTION RATE
7-17-78	6469-79	25,000 gal	25,500	9.4 Bbl/m
8-18 & 19-78	6490-6500 down 2-7/8 tubing	4,000 gal 20% HCl		5 Bbl./mi

T.D.	D.D.	D.P.I.	Class	O	G	Lease
6585	—	—	FEY	—	—	1

NATURAL OPEN FLOW: none
NATURAL ROCK PRESSURE: none
AFTER TREATMENT OPEN FLOW: est. 10 Mcf on 8-19-78
AFTER TREATMENT ROCK PRESSURE: 80 psig on 8-20-78 24 HRS.

REMARKS: Well plugged and abandoned 8-29-78

RECEIVED
MAR 6 1979
PA. GEOLOGIC SURVEY
Oil & Gas Division

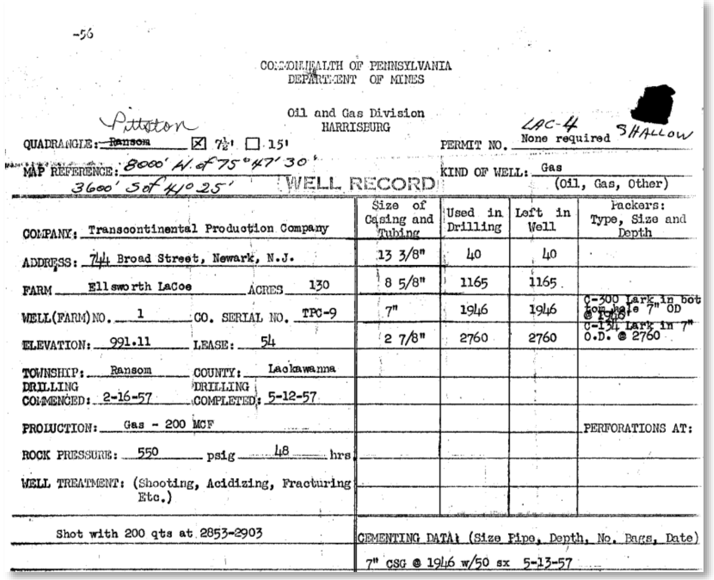
78

Digitizing Well Records

- Quality and format of well regulatory records vary substantially over time and between jurisdictions
- Information contained in each record has generally increased

There is a critical need to digitize well records for both research and regulatory purposes

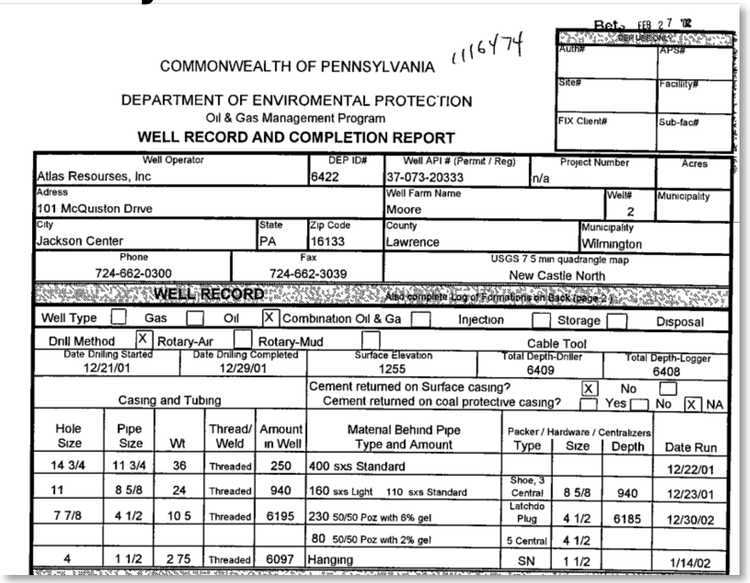
Pennsylvania - 1957


COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF MINES
Oil and Gas Division
HARRISBURG
QUADRANGLE: Ransom Pittston ☒ 7½' ☐ 15'
PERMIT NO. LAC-4 None required SHALLOW
MAP REFERENCE: 8000' W. of 75°47'30" 3600' S. of 41°25'
WELL RECORD
KIND OF WELL: Gas (Oil, Gas, Other)
COMPANY: Transcontinental Production Company
ADDRESS: 744 Broad Street, Newark, N.J.
FARM: Ellsworth LaCoe ACRES 130
WELL (FARM) NO. 1 CO. SERIAL NO. TPC-9
ELEVATION: 991.11 LEASE: 54
TOWNSHIP: Ransom COUNTY: Lackawanna
DRILLING COMMENCED: 2-16-57 DRILLING COMPLETED: 5-12-57
PRODUCTION: Gas - 200 MCF
ROCK PRESSURE: 550 psig 48 hrs
WELL TREATMENT: (Shooting, Acidizing, Fracturing Etc.)
Shot with 200 qts at 2853-2903

Size of Casing and Tubing	Used in Drilling	Left in Well	Packers: Type, Size and Depth
13 3/8"	40	40	
8 5/8"	1165	1165	
7"	1946	1946	C-300 Lark in bot 7" OD @ 1946
2 7/8"	2760	2760	C-134 Lark in 7" O.D. @ 2760

PERFORATIONS AT:
CEMENTING DATA: (Size Pipe, Depth, No. Bags, Date)
7" csg @ 1946 w/50 sx 5-13-57

Pennsylvania - 2002


COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIROMENTAL PROTECTION
Oil & Gas Management Program
WELL RECORD AND COMPLETION REPORT

Well Operator	DEP ID#	Well API # (Permit / Reg)	Project Number	Acres
Atlas Resourses, Inc	6422	37-073-20333	n/a	

Adress: 101 McQuiston Drive | Well Farm Name: Moore | Well# 2 | Municipality
City: Jackson Center | State: PA | Zip Code: 16133 | County: Lawrence | Municipality: Wilmington
Phone: 724-662-0300 | Fax: 724-662-3039 | USGS 7.5 min quadrangle map: New Castle North

WELL RECORD
Well Type ☐ Gas ☐ Oil ☒ Combination Oil & Gas ☐ Injection ☐ Storage ☐ Disposal
Drill Method ☒ Rotary-Air ☐ Rotary-Mud ☐ Cable Tool
Date Drilling Started 12/21/01 | Date Drilling Completed 12/29/01 | Surface Elevation 1255 | Total Depth-Driller 6409 | Total Depth-Logger 6408
Cement returned on Surface casing? ☒ Yes ☐ No
Cement returned on coal protective casing? ☐ Yes ☐ No ☒ NA

Casing and Tubing

Hole Size	Pipe Size	Wt	Thread/Weld	Amount in Well	Material Behind Pipe Type and Amount	Packer / Hardware / Centralizers Type	Size	Depth	Date Run
14 3/4	11 3/4	36	Threaded	250	400 sxs Standard				12/22/01
11	8 5/8	24	Threaded	940	160 sxs Light 110 sxs Standard	Shoe, 3 Central	8 5/8	940	12/23/01
7 7/8	4 1/2	10.5	Threaded	6195	230 50/50 Poz with 6% gel	Latchdo Plug	4 1/2	6185	12/30/02
					80 50/50 Poz with 2% gel	5 Central	4 1/2		
4	1 1/2	2.75	Threaded	6097	Hanging	SN	1 1/2		1/14/02

Technological Solutions Exist

- **Optical Character Recognition (OCR)**
  - Algorithmic conversion of text into machine readable format
- **Large Language Models (LLMs)**
  - Neural networks trained on large volumes of text that can summarize and answer questions about documents
- Numerous public and proprietary tools available
- Performance relies on specific training

Goal is to create a tool that applies custom OCR and LLM approaches to facilitate historic record digitization

OGRRE: Oil and Gas Regulatory Record digitizEr

- First prototype released in May 2024
- Hosted on Google Cloud – Leverages Document AI

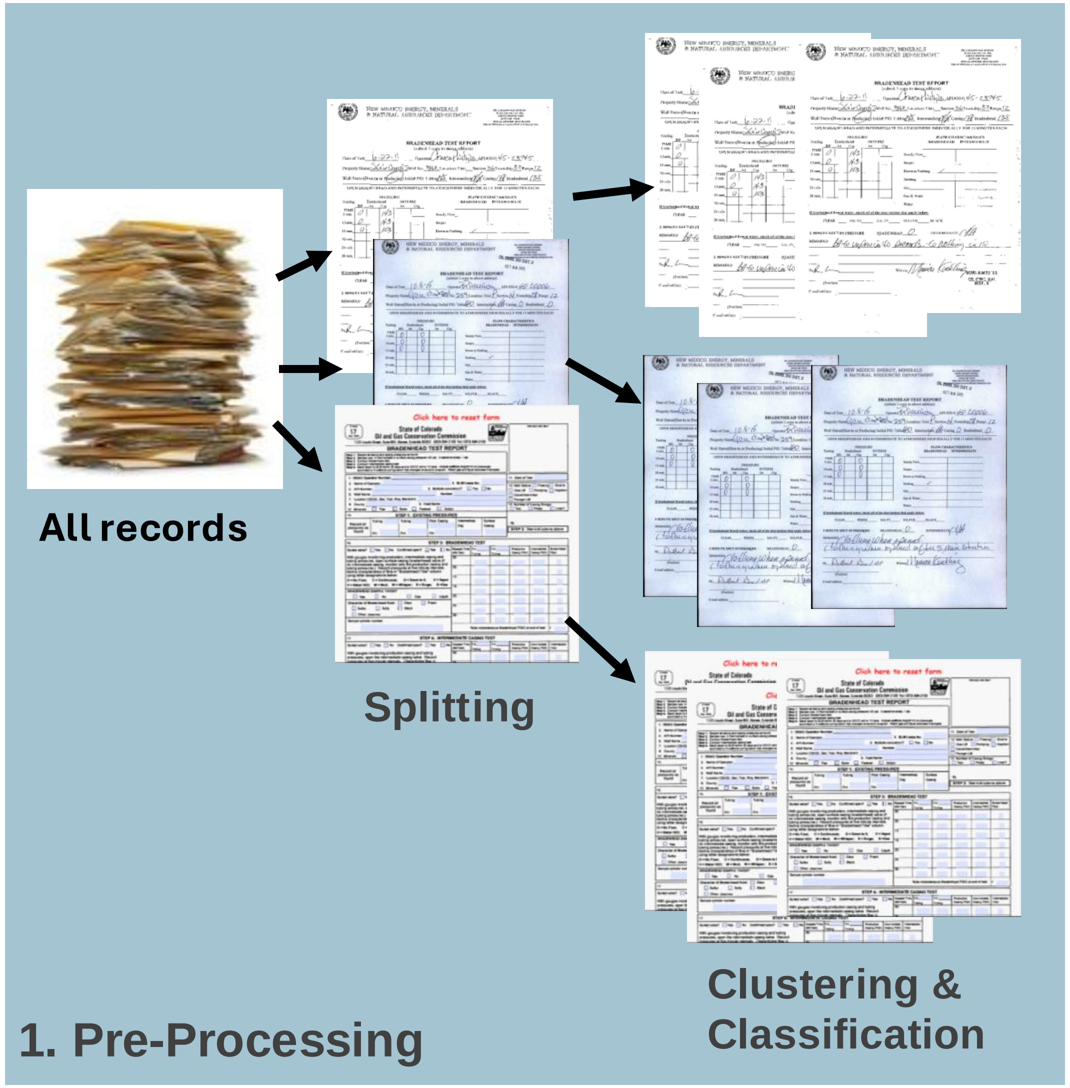
Illinois State Geological Survey Collaboration

Prairie Research Institute
Illinois State Geological Survey

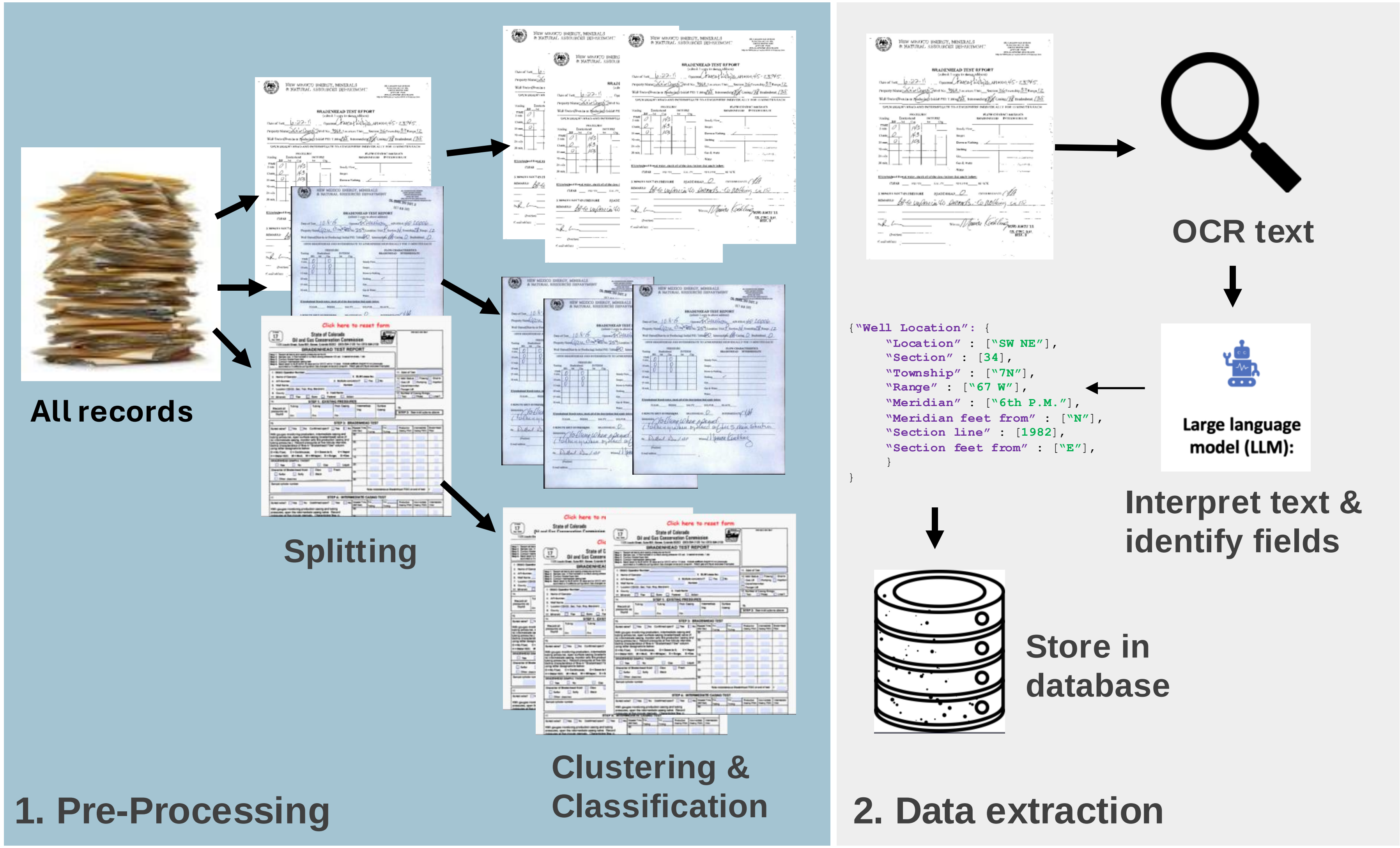
- Three summer interns using OGRRE to digitize well completion reports from ~500 high priority wells in Illinois
- Iteratively improving tool design

Google Cloud

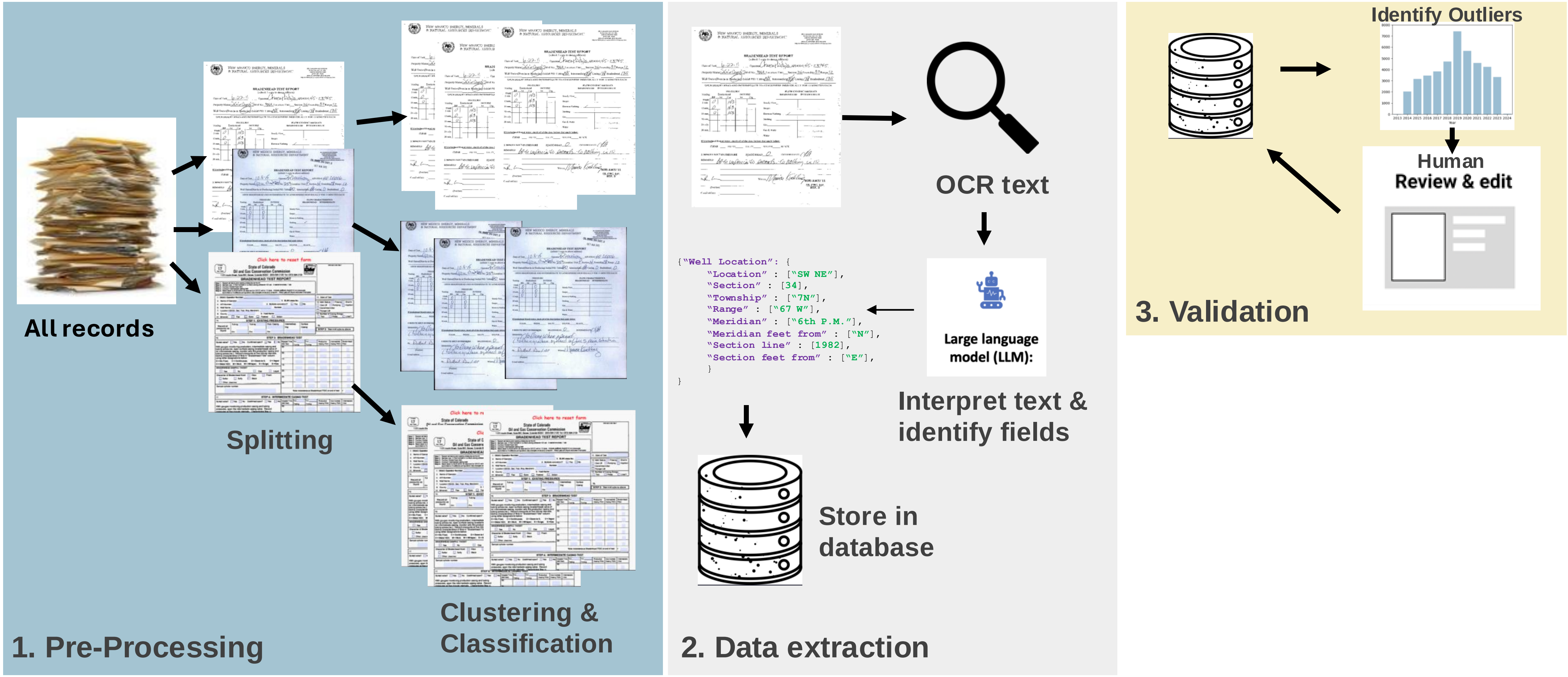
Complete Workflow

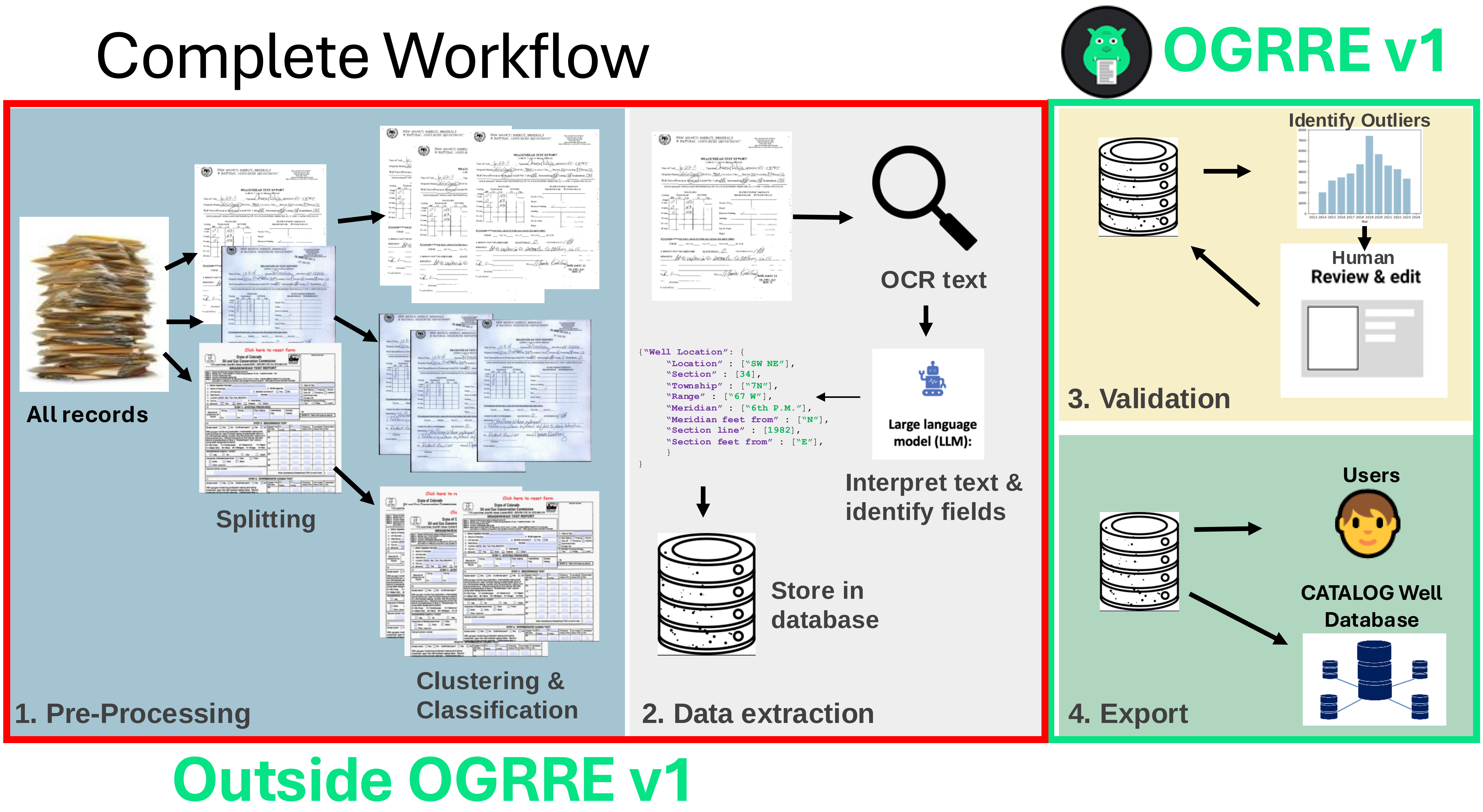


Complete Workflow



Complete Workflow

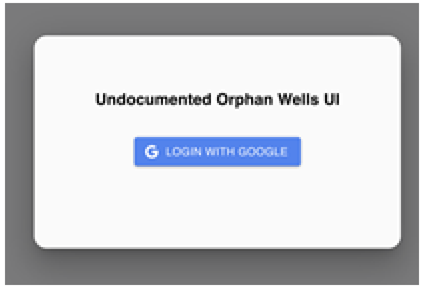




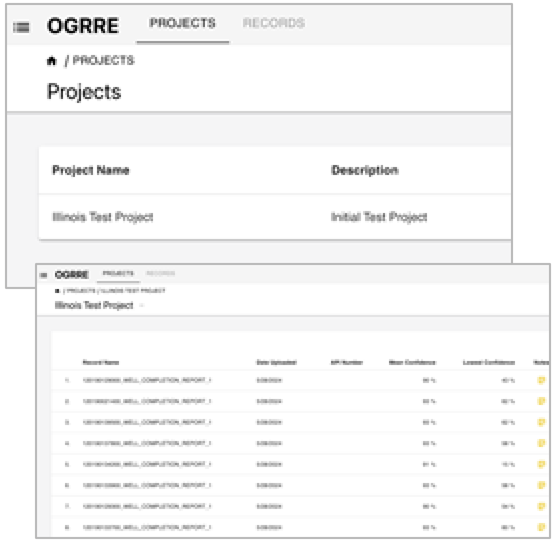
Complete Workflow
OGRRE v1
All records
Splitting
Clustering &
Classification
1. Pre-Processing
OCR text
{"Well Location": {
"Location" : ["SW NE"],
"Section" : [34],
"Township" : ["7N"],
"Range" : ["67 W"],
"Meridian" : ["6th P.M."],
"Meridian feet from" : ["N"],
"Section line" : [1982],
"Section feet from" : ["E"],
}
}
Large language model (LLM):
Interpret text & identify fields
Store in database
2. Data extraction
Identify Outliers
Human Review & edit
3. Validation
Users
CATALOG Well Database
4. Export
Outside OGRRE v1

Current OGRRE Workflow

Log in

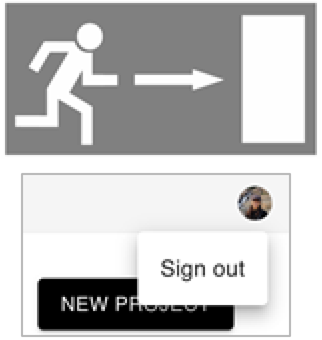


Choose project
(Slides 4 - 6)



Review records
(Slides 8-13)

Sign out

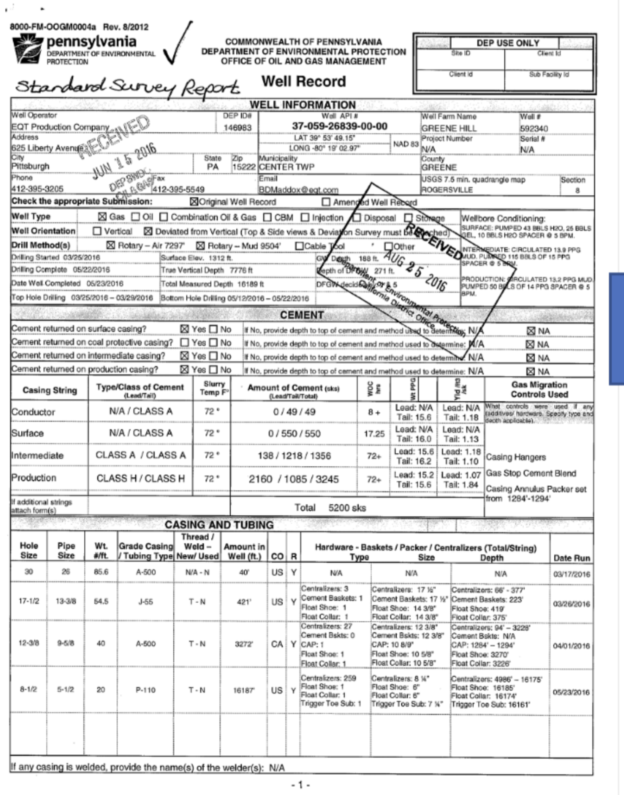


Export records
(Slide 7)

Oil and Gas Regulatory Record Digitizer (OGRRE)

Tool Demo

Multimodal large language models for historical records



8000-FM-OOGM0004a Rev. 8/2012

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
OFFICE OF OIL AND GAS MANAGEMENT

DEP USE ONLY	
Site ID	Client Id
Client Id	Sub Facility Id

Standard Survey Report

Well Record

WELL INFORMATION

Well Operator: EQT Production Company	DEP ID#: 146983	Well API #: 37-059-26839-00-00		Well Farm Name: GREENE HILL	Well #: 592340
Address: 625 Liberty Avenue		LAT 39° 53' 49.15" / LONG -80° 19' 02.97"	NAD 83	Project Number: N/A	Serial #: N/A
City: Pittsburgh	State: PA / Zip: 15222	Municipality: CENTER TWP		County: GREENE	
Phone: 412-395-3205	Fax: 412-395-5549	Email: BDMaddox@eqt.com		USGS 7.5 min. quadrangle map: ROGERSVILLE	Section: 8

RECEIVED JUN 15 2016 DEP SWRO OIL & GAS

Check the appropriate Submission: ☒ Original Well Record ☐ Amended Well Record

Well Type: ☒ Gas ☐ Oil ☐ Combination Oil & Gas ☐ CBM ☐ Injection ☐ Disposal ☐ Storage

Well Orientation: ☐ Vertical ☒ Deviated from Vertical (Top & Side views & Deviation Survey must be attached)

Drill Method(s): ☒ Rotary – Air 7297' ☒ Rotary – Mud 9504' ☐ Cable Tool ☐ Other

Drilling Started 03/25/2016 · Surface Elev. 1312 ft. · GW Depth 188 ft.

Drilling Complete 05/22/2016 · True Vertical Depth 7776 ft · Depth of DFGW 271 ft.

Date Well Completed 05/23/2016 · Total Measured Depth 16189 ft · DFGW decided

Top Hole Drilling 03/25/2016 – 03/29/2016 · Bottom Hole Drilling 05/12/2016 – 05/22/2016

Wellbore Conditioning: SURFACE: PUMPED 43 BBLS H2O, 25 BBLS GEL, 10 BBLS H2O SPACER @ 5 BPM. INTERMEDIATE: CIRCULATED 13.9 PPG MUD. PUMPED 115 BBLS OF 15 PPG SPACER @ 5 BPM. PRODUCTION: CIRCULATED 13.2 PPG MUD. PUMPED 50 BBLS OF 14 PPG SPACER @ 5 BPM.

RECEIVED AUG 25 2016 Department of Environmental Protection California District Office

CEMENT

Cement returned on surface casing? ☒ Yes ☐ No — If No, provide depth to top of cement and method used to determine: N/A ☒ NA

Cement returned on coal protective casing? ☐ Yes ☐ No — If No, provide depth to top of cement and method used to determine: N/A ☒ NA

Cement returned on intermediate casing? ☒ Yes ☐ No — If No, provide depth to top of cement and method used to determine: N/A ☒ NA

Cement returned on production casing? ☒ Yes ☐ No — If No, provide depth to top of cement and method used to determine: N/A ☒ NA

Casing String	Type/Class of Cement (Lead/Tail)	Slurry Temp F°	Amount of Cement (sks) (Lead/Tail/Total)	WOC hrs	Wt PPG	Yld ft3/sk	Gas Migration Controls Used
Conductor	N/A / CLASS A	72°	0 / 49 / 49	8 +	Lead: N/A Tail: 15.6	Lead: N/A Tail: 1.18	What controls were used if any (additives/ hardware. Specify type and depth applicable).
Surface	N/A / CLASS A	72°	0 / 550 / 550	17.25	Lead: N/A Tail: 16.0	Lead: N/A Tail: 1.13	
Intermediate	CLASS A / CLASS A	72°	138 / 1218 / 1356	72+	Lead: 15.6 Tail: 16.2	Lead: 1.18 Tail: 1.10	Casing Hangers
Production	CLASS H / CLASS H	72°	2160 / 1085 / 3245	72+	Lead: 15.2 Tail: 15.6	Lead: 1.07 Tail: 1.84	Gas Stop Cement Blend; Casing Annulus Packer set from 1284'-1294'
If additional strings attach form(s)			Total 5200 sks				

CASING AND TUBING

Hole Size	Pipe Size	Wt. #/ft.	Grade Casing / Tubing Type	Thread / Weld – New/ Used	Amount in Well (ft.)	CO	R	Hardware - Baskets / Packer / Centralizers (Total/String) Type	Size	Depth	Date Run
30	26	85.6	A-500	N/A - N	40'	US	Y	N/A	N/A	N/A	03/17/2016
17-1/2	13-3/8	54.5	J-55	T - N	421'	US	Y	Centralizers: 3 Cement Baskets: 1 Float Shoe: 1 Float Collar: 1	Centralizers: 17 ½" Cement Baskets: 17 ½" Float Shoe: 14 3/8" Float Collar: 14 3/8"	Centralizers: 66' - 377' Cement Baskets: 223' Float Shoe: 419' Float Collar: 375'	03/26/2016
12-3/8	9-5/8	40	A-500	T - N	3272'	CA	Y	Centralizers: 27 Cement Bskts: 0 CAP: 1 Float Shoe: 1 Float Collar: 1	Centralizers: 12 3/8" Cement Bskts: 12 3/8" CAP: 10 8/9" Float Shoe: 10 5/8" Float Collar: 10 5/8"	Centralizers: 94' – 3228' Cement Bskts: N/A CAP: 1284' – 1294' Float Shoe: 3270' Float Collar: 3226'	04/01/2016
8-1/2	5-1/2	20	P-110	T - N	16187'	US	Y	Centralizers: 259 Float Shoe: 1 Float Collar: 1 Trigger Toe Sub: 1	Centralizers: 8 ¼" Float Shoe: 6" Float Collar: 6" Trigger Toe Sub: 7 ¼"	Centralizers: 4986' – 16175' Float Shoe: 16185' Float Collar: 16174' Trigger Toe Sub: 16161'	05/23/2016

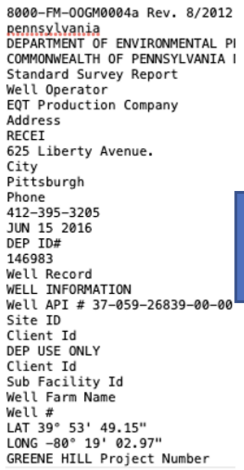
If any casing is welded, provide the name(s) of the welder(s): N/A

- 1 -

1. Document image

OCR

2. Semi-structured text



8000-FM-OOGM0004a Rev. 8/2012
pennsylvania
DEPARTMENT OF ENVIRONMENTAL PI
COMMONWEALTH OF PENNSYLVANIA I
Standard Survey Report
Well Operator
EQT Production Company
Address
RECEI
625 Liberty Avenue.
City
Pittsburgh
Phone
412-395-3205
JUN 15 2016
DEP ID#
146983
Well Record
WELL INFORMATION
Well API # 37-059-26839-00-00
Site ID
Client Id
DEP USE ONLY
Client Id
Sub Facility Id
Well Farm Name
Well #
LAT 39° 53' 49.15"
LONG -80° 19' 02.97"
GREENE HILL Project Number

LLM

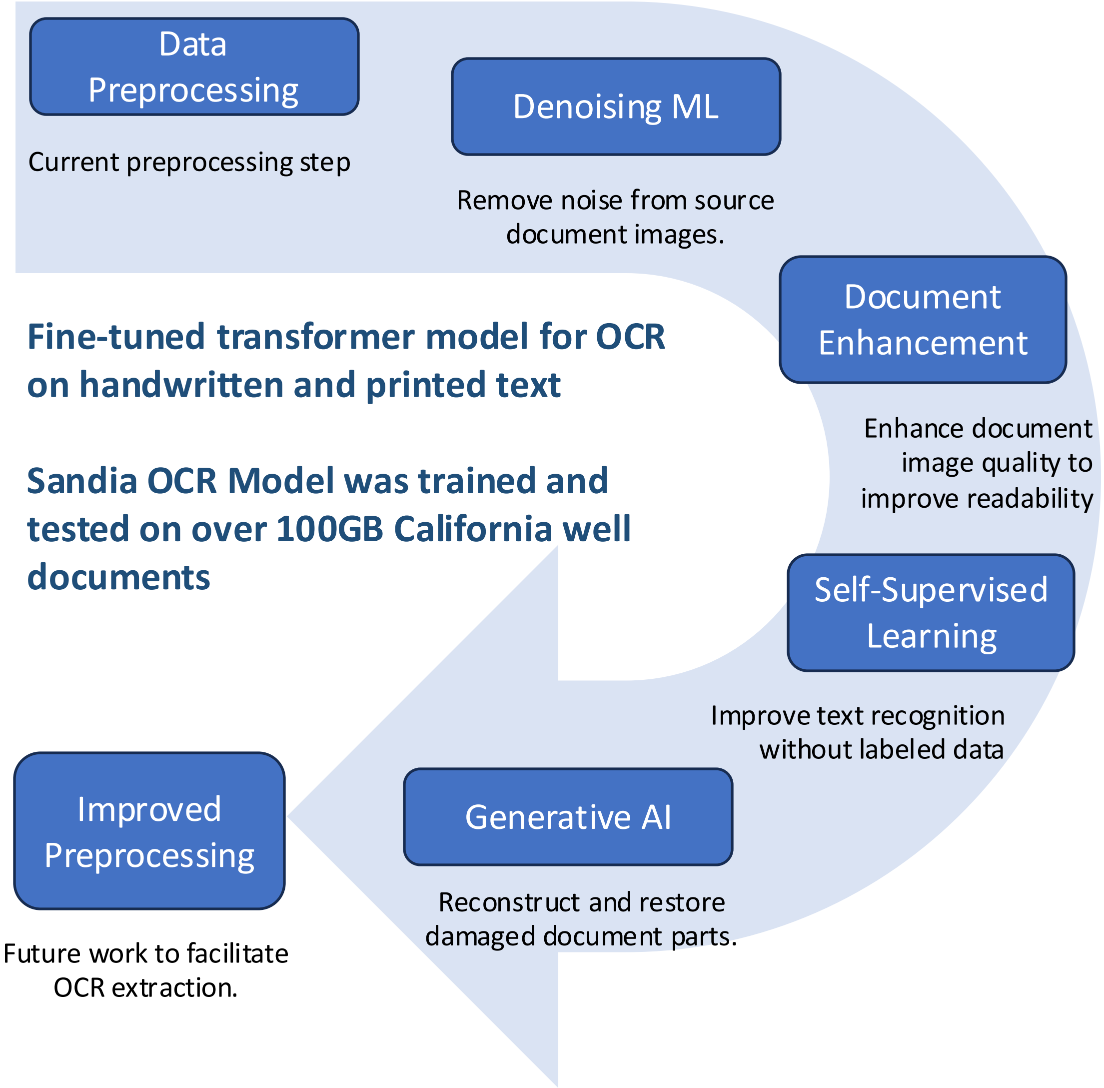
3. Structured Well Information

{ "latitude": 39.896986
"longitude": -80.3174
"depth": 7776}

We have had early success extracting well characterization information from image-based documents using optical character recognition (OCR) and large language models (LLMs) like ChatGPT

OCR for orphaned well record analysis

Current Process



Fine-tuned transformer model for OCR on handwritten and printed text

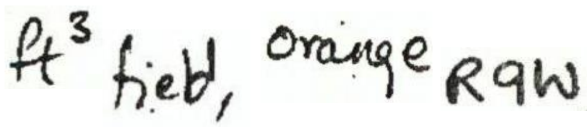
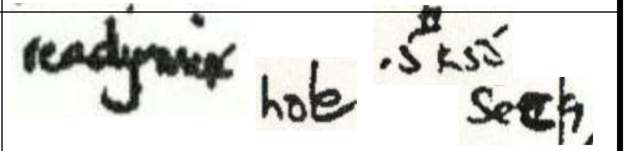
Sandia OCR Model was trained and tested on over 100GB California well documents

Objectives

Efficient Text Extraction: Automate and streamline the process of extracting text from legacy handwritten documents which are often difficult to read and digitize manually.

Integration with LLM: Use the extracted text with Large Language Models (LLMs) to find lost oil and gas wells, contributing to climate change mitigation efforts by identifying and addressing potential environmental hazards.

Results: 0.89 accuracy

Sandia OCR Correctly Labeled	Sandia OCR Incorrectly Labeled
	

Future Work

- Integration with LANL Language Model and LBL Web Application
- Predict misreads with LMs integrated into the scope of MM-Model
- Scaling and fine-tuning the transformer model

Methane detection and Emissions Quantification

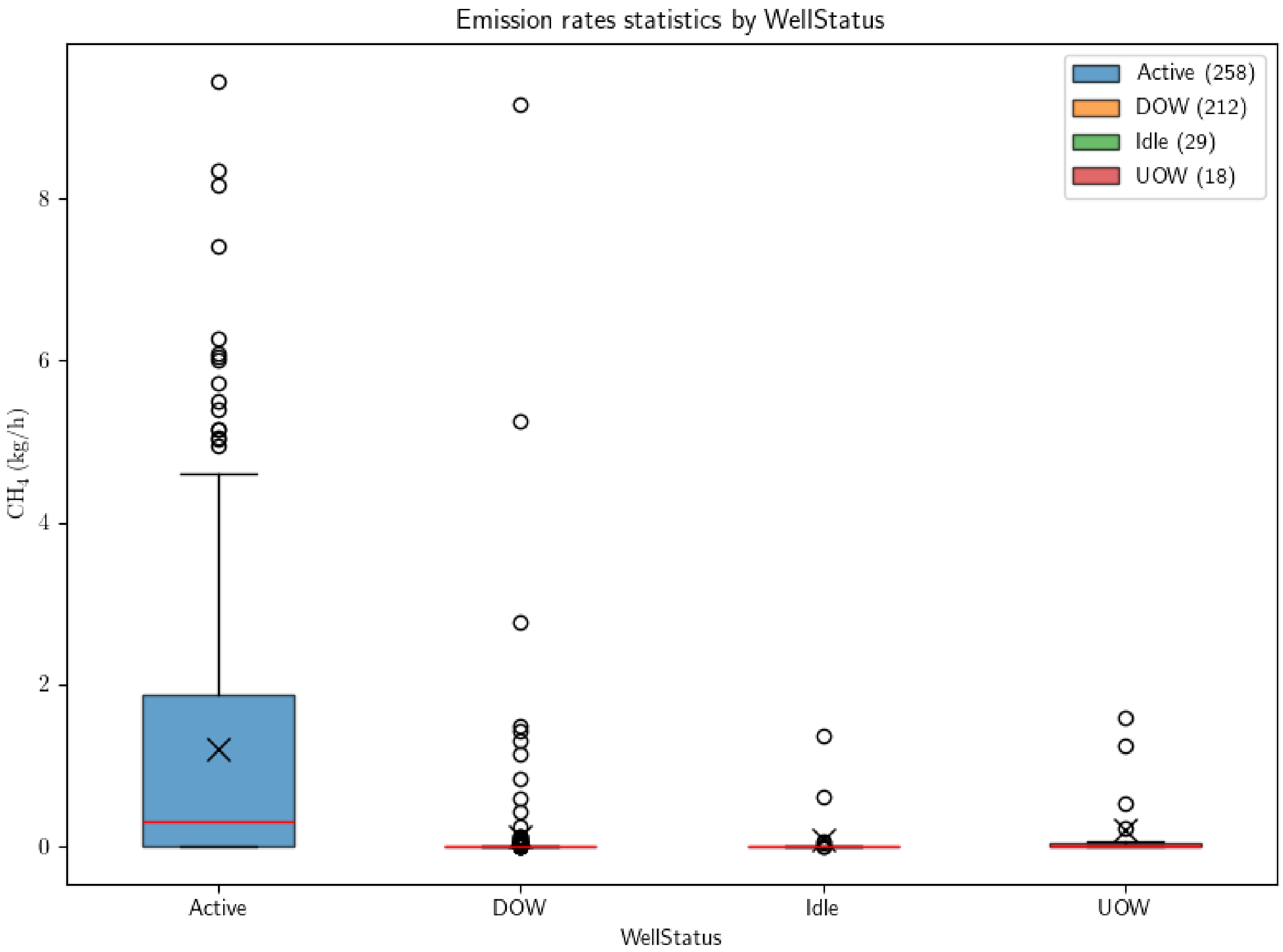
Sebastien Biraud[1] (SCBiraud@lbl.gov), Mavendra Dubey[2], Mohit Dubey[1], Emily Follansbee[2], James Lee[2], Andrew Moyes[1], Natalie Pekney[3], Matthew Reeder[3], Andre Santos[1]

[1] Lawrence Berkeley National Laboratory (LBNL)
[2] Los Alamos National Laboratory (LANL)
[3] National Energy and Technology Laboratory (NETL)

WP1 Objectives

- Provide DOI with **accurate, cost-effective methane measurement methods that can be used to report well emission reduction values** back to congress as required by the BIL language.
- Most wells are low emitters; large number of emitting wells adds to significant emissions.
- Flow rate is difficult to measurement to make without complex equipment. Concentration is a much simpler measurement to make.
- The low level of emissions from individual wells are a challenge for satellites thus require new technologies.
- Understand methane emission distributions + uncertainties from orphan well populations.
- Understand the temporal component of well emissions and the related uncertainty.

Emission Statistics



Well Status	Median (g/h)	Mean (g/h)
Active	312	1201±1780
DOW	0	123±768
Idle	0	71±271
UOW	3	206±461

Field campaigns in CA, OH, OK, PA, NM, and TX. N=517 wells

Methane Detection and Quantification Activities

- Quantitative measurement of UOW methane emissions
- Backpack-based and drone measurements
- Used before and after P&A data
- Validates effective P&A
- Provides DOI with important metric of impact of program
- Applies to both undocumented and documented P&A programs

<u>Need</u>: states and other stakeholders currently lack a rapid method for measuring methane emissions and robust methods for pinpointing leaking undocumented orphan wells

Comparative assessment of commercial and research methods to quantify methane leak rate for UOW

Method	FLIR	SEMTECH	Static Chamber	Dynamic Chamber	GPM	Vent Buster	UAV	EPA OTM 33A	FAST
Hardware	$100K	$40K	$10K	$25K	>$5K	$50K	$60K	$10K	<$35K
Range (g/h)	>100	1-1000	0.1-10	0.1-200	>100	>100	50-1500	>50	1-1000
Accuracy	Low	High	High	High	Low	High	High	Low	High
Size	Small	Small	Large	Large	Large	Large	Large	Large	Small
Labor	Low	Low	High	High	Low	High	High	Low	Low
Safety	High	Low	Low	Low	High	Low	High	High	High

FAST Method: Gaussian plume model framework

Methodology is based on Gaussian Plume Model to estimate emission rates from measurements of:

- CH_4 atmospheric concentrations
- 3D wind observations

We assume: y=0 (along the plume centerline) and z=H (source/receptor at same height)

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \quad \text{where:}$$

We can then solve for the estimated flow rate (Q_{est}) as a function of time averaged concentration ($\overline{C}$) and wind speed ($\overline{u}$):

$$Q_{est} = \overline{C} \cdot \overline{u} \cdot K, \quad \text{where } K = \frac{2\pi\sigma_y\sigma_z}{\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)}$$

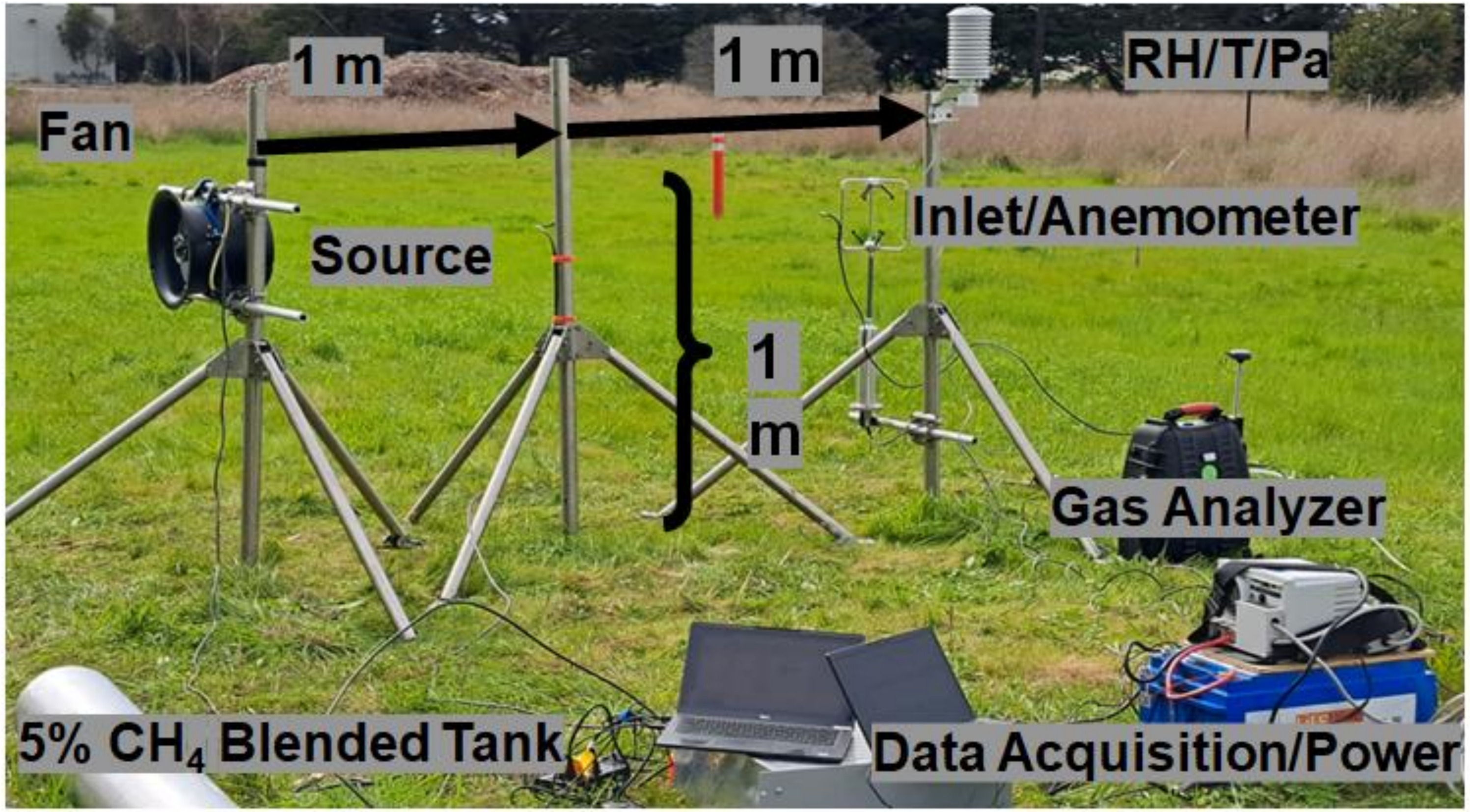
measured ???

FAST Method: K coefficient estimated from control release

In contrast to previous studies, we investigated the application of “forced advection” by using a fan to reduce variability in U and C associated with wind conditions (fan is isotropic and leads to the creation of a Gaussian distribution within the flow)

FAST: Forced Advection Sampling Technique (Dubey et al., 2024 – in prep)

Dominant
wind direction



FAST Method: K coefficient estimated from control release

Control Release Settings

- Range: 1 g/hr to 40 g/hr (using 5% CH_4 tank and diluted with UHP N2).
- Target emission rates: 1, 2, 5, 10, 20, 40 g/hr CH_4

$$K = \frac{Q_{rel}}{C\,.\,u}$$

Data acquisition - 5 minutes at 3 Fan settings:

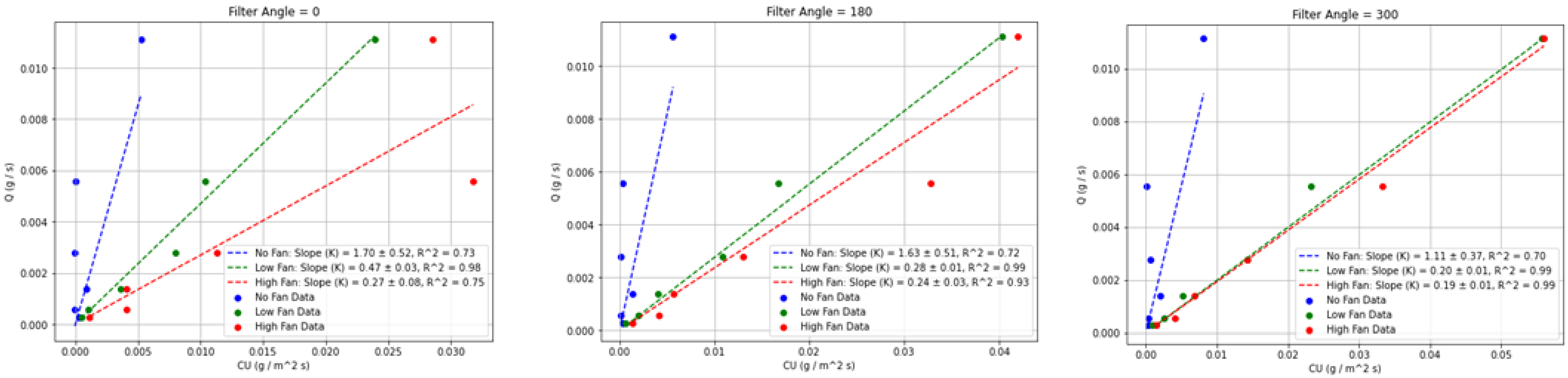
-No Fan

-Low Fan setting (~3 m/s)

-High Fan setting (~5 m/s)

-

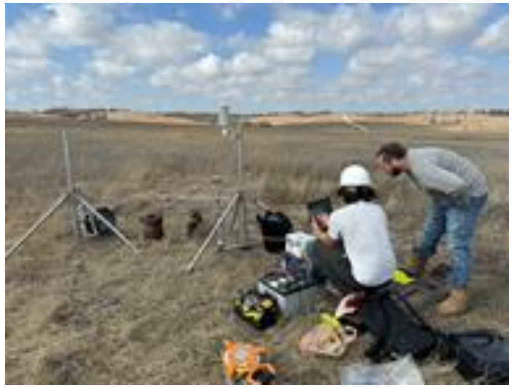
Data filtered to minimize impact of crosswind, because of strong winds on day of experiment (1-5 m/s with gusts up to 10 m/s)



Plotting C * U vs. Q_{true} allows us to estimate values of K. With Fan OFF, data fit is poor ($R^2 < 0.75$) due to variability in wind. With Fan ON, we can fit values of **K ~ 0.20 (Low Fan) and 0.19 (High Fan)**

Field Campaigns: sensors tested

- ✓ OGI camera (FLIR, cost: $100k)
- ✓ In situ HIGH-FLOW2 sensor (SEMTECH, cost: ~$40K)
- ✓ ***FAST method***: In situ CH_4 sensors Conc. (Picarro, model: G4302, cost: ~$45K) + In situ wind sensor (Gill, model: R3-50; cost: ~$10k)
- ✓ LIDAR (Xplorobot, cost: ~$150 scanned well)
- ✓ Gas rover (Bascom-Turner, cost: ~$4.5k)



Field Campaign: Reality Check #1 (Texas)

<u>Charge</u>: Quantify methane emissions at 11 Documented Orphaned Wells (DOW) before Plugging and Abandonment (P&A)

<u>Location</u>: US Forest Service (Angelina and Sabine Districts)

<u>Timeline</u>: Feb 5-7, 2024

<u>Approach</u>: FLIR / SEMTECH / FAST / XploRobot / EPA (2-point)

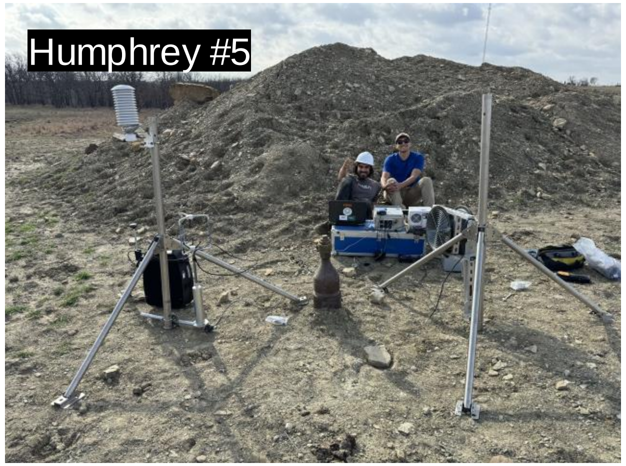
Field Campaign: Reality Check #2 (Oklahoma)

Charge: Quantify methane emissions at Documented and Undocumented Orphaned Wells (DOW and UOW)

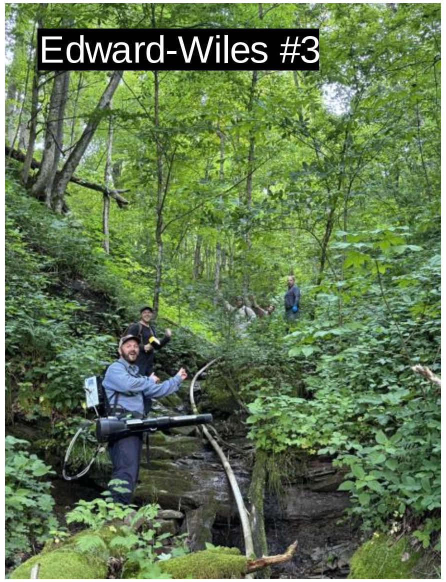
Location: Osage County

Timeline: March 11-15, 2024

Approach: FLIR / SEMTECH / FAST / XploRobot



Field Campaign: Reality Check #3 (Ohio)



Charge: Quantify methane emissions at Documented and Undocumented Orphaned Wells (DOW and UOW)

Location: Osage County

Timeline: May 19-24, 2024

Approach: FLIR / SEMTECH / FAST / XploRobot

Field Campaigns: Results

Date	Well ID	SEMTECH (g/hr)	FAST (0 Filter) (g/hr)	FAST (180 Filter) (g/hr)	FAST (300 Filter) (g/hr)
2024-02-06	Rayburn #7 (Lufkin, TX)	**2.9 ± 0.0**	Low: 5.2 ± 4.5 No: 0.8 ± 2.8	Low: 3.3 ± 2.7 No: 0.9 ± 3.1	**Low: 2.6 ± 1.9** No: 0.6 ± 1.8
2024-02-07	Connor #92 (Lufkin, TX)	**1.0 ± 0.3**	Low: 1.0 ± 1.4 No: 0.4 ± 2.4	Low: 0.7 ± 0.9 No: 1.1 ± 3.8	**Low: 0.5± 0.7** No: 1.3 ± 3.4
2024-03-14	Humphrey #5 (Barnsdall, OK)	**2.0 ± 0.04**	High: 2.8 ± 1.8 Low: 5.6 ± 3.7 No: 15.0 ± 22.8	High: 2.5 ± 1.5 Low: 3.4 ± 2.2 No: 14.4 ± 21.9	**High: 2.0 ± 1.1** Low: 2.5 ± 1.5 No: 10.0 ± 15.1
2024-03-14	Hooper #41 (Barnsdall, OK)	**70.1 ± 95.5**	High: 12.1 ± 15.3 Low: 20.2 ± 31.4 No: 2.6 ± 15.8	High: 10.8 ± 13.3 Low: 12.0 ± 18.6 No: 2.6 ± 15.6	**High: 9.3 ± 10.4** Low: 9.9 ± 12.7 No: 1.0 ± 4.0

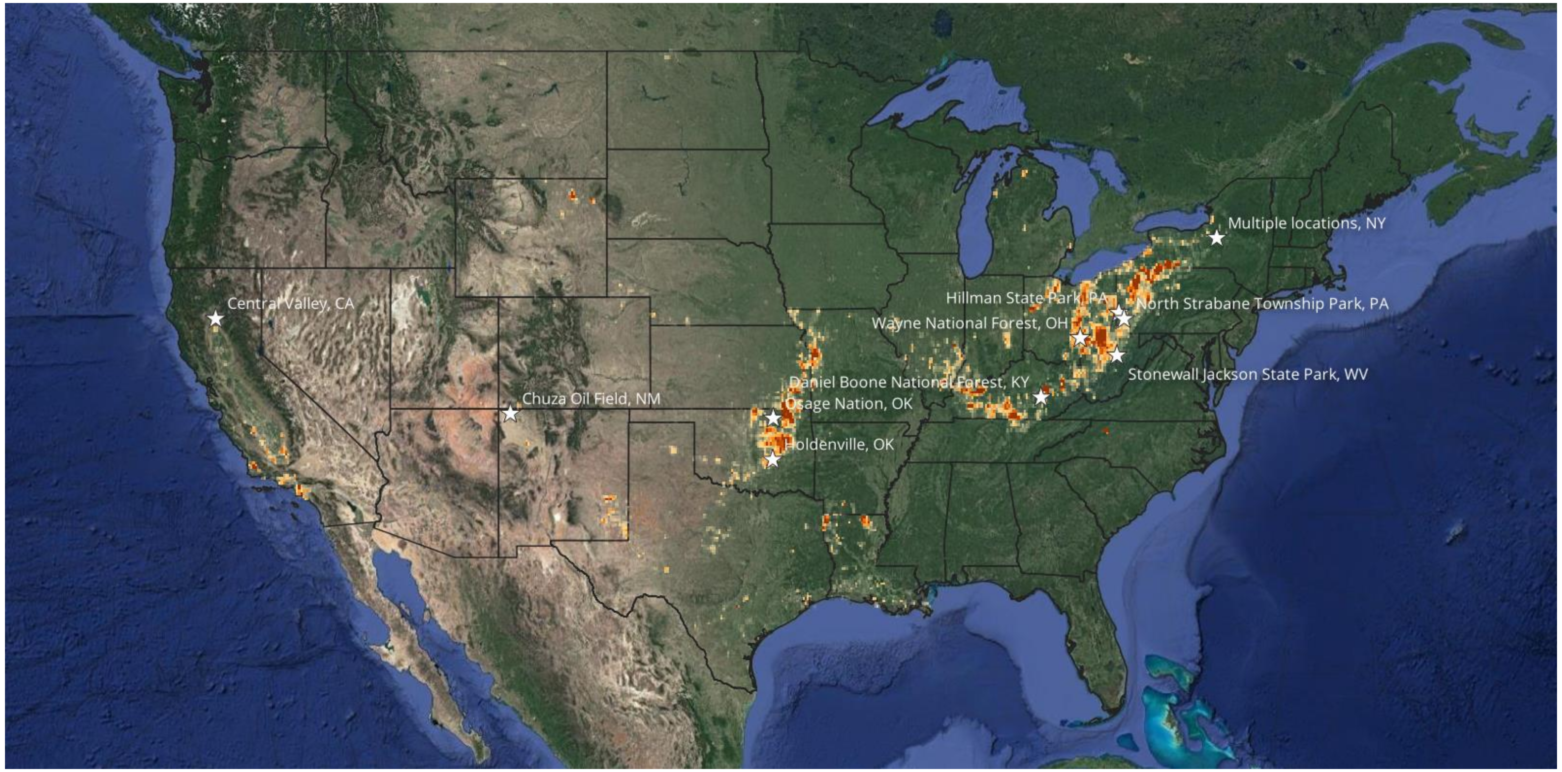
Next Steps

- Forced advection (Fan) enhances results compared to ambient wind conditions (No Fan)
- Uncertainties in emissions, though sizable compared to SEMTECH, remain reasonable for quick screening
- Further analysis required on wind direction filtering and optimal averaging windows to improve existing results
- Future work includes validating method with low-cost sensors, in order to bring down cost and establish standard emission quantification protocol
- Expand the scope of field campaigns to thoroughly validate the method across a spectrum of real-world scenarios
- Characterize temporal variability of methane emissions from DOWs and UOWs

Field Teams

Christine Downs (SNL, cdowns@sandia.gov), Eric Guiltinan, Mavendra Dubey (LANL), Sebastien Biraud, Andre Santos, Yuxin Wu (LBNL), Matthew Reader (NETL), Jacob Trueblood (LLNL)

- rapidly plan, collect, and interpret UOW field surveys in novel areas or for underserved communities
- build a database of real-world geophysical and emissions data
- early testing of guidelines and workflows in various real-world environments
- curate field data into a database for eventual public consumption

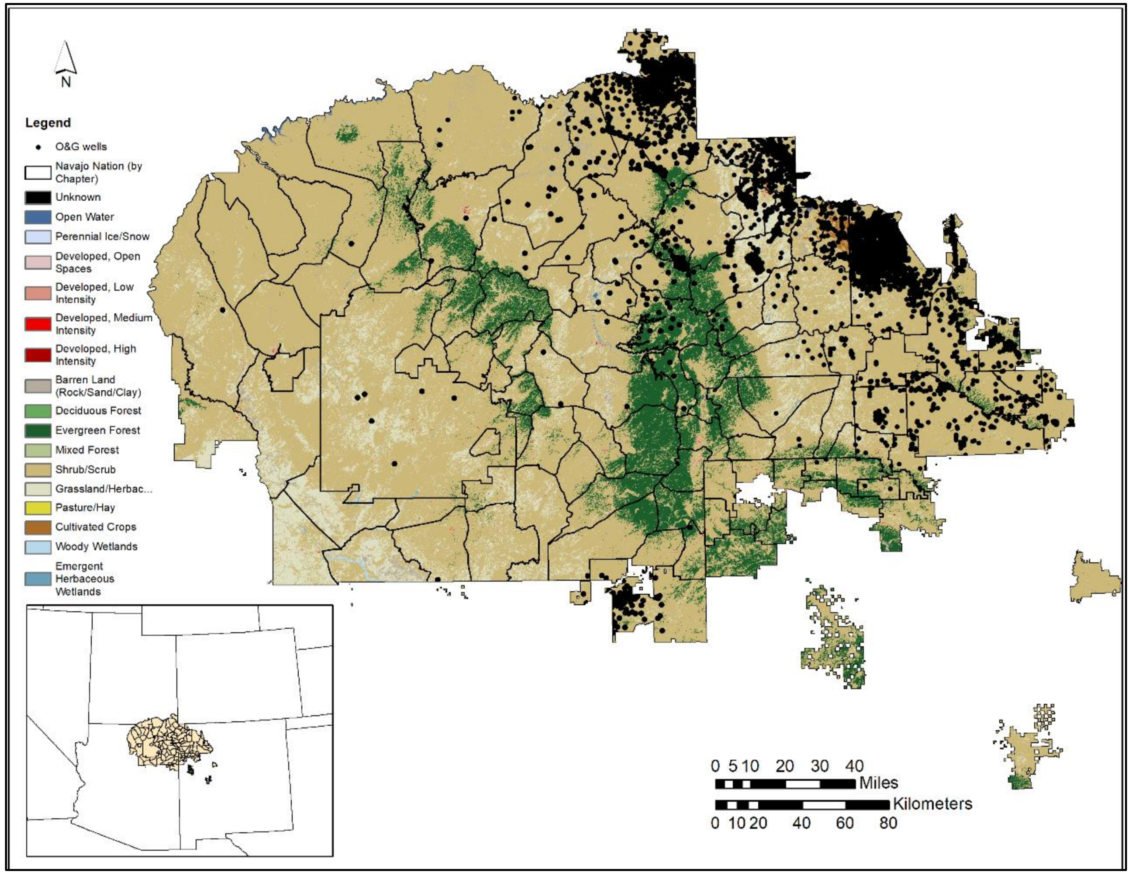


Locations of past, current and future field work across various terrain types. Heat map of O&G wells from NETL's working national database.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525

Navajo Nation

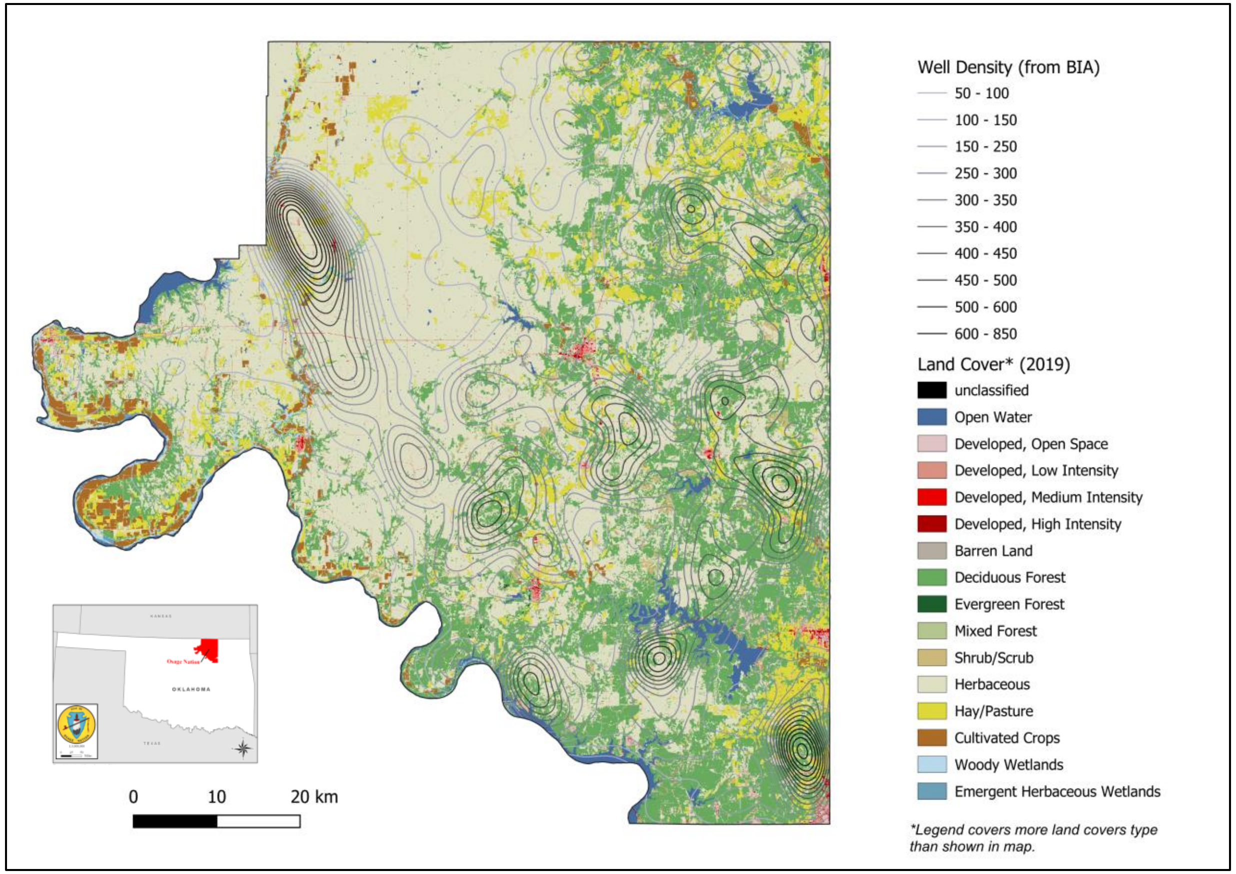
- 133,639 documented wells (*5595 in NN*)
    - 124,215 O&G (44,705 abandoned)
    - 2,321 additional abandoned



Terrain: steep canyons and flat mesas within a semi-arid desert

Osage Nation

- 43,822 documented wells (*BIA*)
    - 28,323 O&G (13,370 abandoned)
    - 2,347 additional abandoned

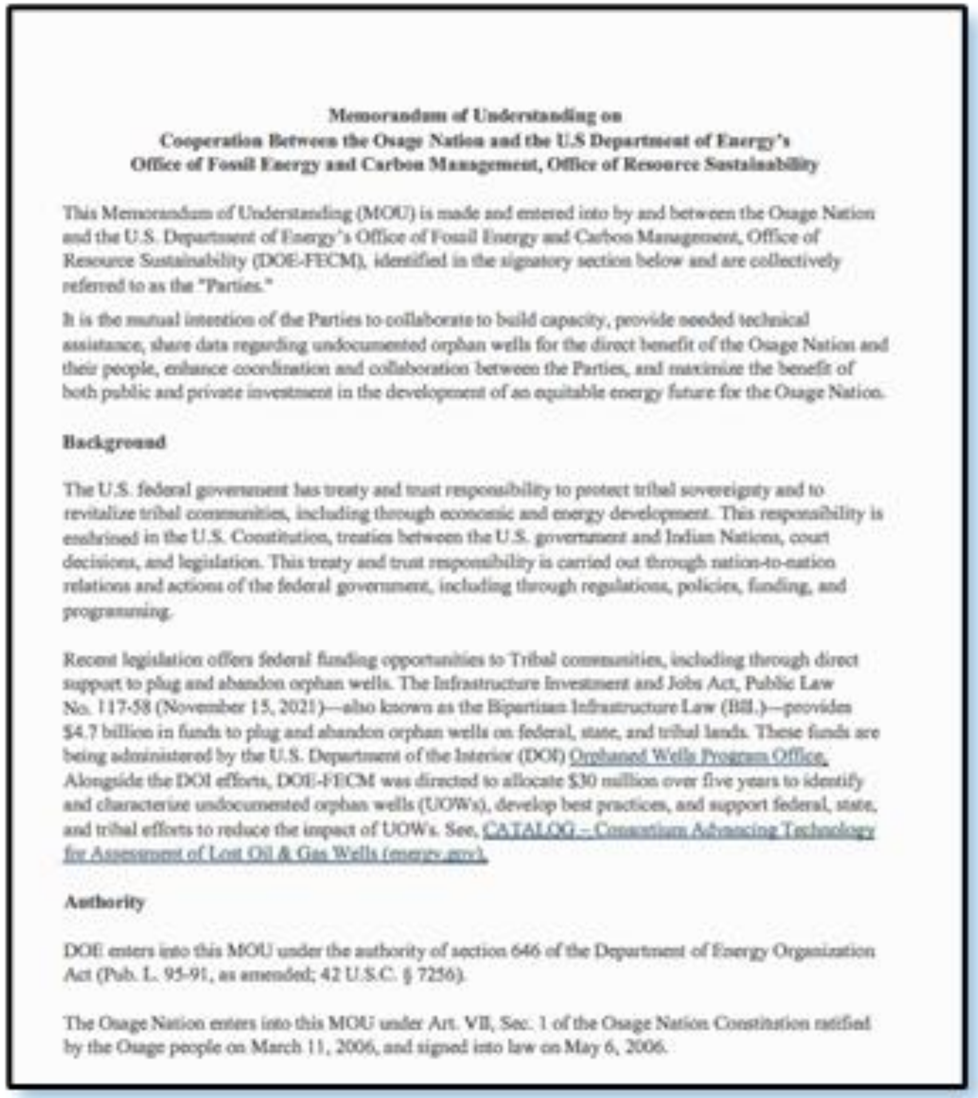


Terrain: herbaceous, deciduous forest and hay/pasture

A framework for collaboration

Memorandum of Understanding between FECM and Osage Nation and Navajo Nation:

- ***Build*** capacity, provide needed technical assistance.
- ***Search*** for undocumented orphan wells using desktop and field-based methodologies.
- ***Share*** all collected data and resulting interpretation.
- ***Support*** the development of the Osage Nation's own UOW identification capabilities.



Memorandum of Understanding on Cooperation Between the Osage Nation and the U.S Department of Energy's Office of Fossil Energy and Carbon Management, Office of Resource Sustainability

This Memorandum of Understanding (MOU) is made and entered into by and between the Osage Nation and the U.S. Department of Energy's Office of Fossil Energy and Carbon Management, Office of Resource Sustainability (DOE-FECM), identified in the signatory section below and are collectively referred to as the "Parties."

It is the mutual intention of the Parties to collaborate to build capacity, provide needed technical assistance, share data regarding undocumented orphan wells for the direct benefit of the Osage Nation and their people, enhance coordination and collaboration between the Parties, and maximize the benefit of both public and private investment in the development of an equitable energy future for the Osage Nation.

Background

The U.S. federal government has treaty and trust responsibility to protect tribal sovereignty and to revitalize tribal communities, including through economic and energy development. This responsibility is enshrined in the U.S. Constitution, treaties between the U.S. government and Indian Nations, court decisions, and legislation. This treaty and trust responsibility is carried out through nation-to-nation relations and actions of the federal government, including through regulations, policies, funding, and programming.

Recent legislation offers federal funding opportunities to Tribal communities, including through direct support to plug and abandon orphan wells. The Infrastructure Investment and Jobs Act, Public Law No. 117-58 (November 15, 2021)—also known as the Bipartisan Infrastructure Law (BIL)—provides $4.7 billion in funds to plug and abandon orphan wells on federal, state, and tribal lands. These funds are being administered by the U.S. Department of the Interior (DOI) Orphaned Wells Program Office. Alongside the DOI efforts, DOE-FECM was directed to allocate $30 million over five years to identify and characterize undocumented orphan wells (UOWs), develop best practices, and support federal, state, and tribal efforts to reduce the impact of UOWs. See, CATALOG – Consortium Advancing Technology for Assessment of Lost Oil & Gas Wells (energy.gov).

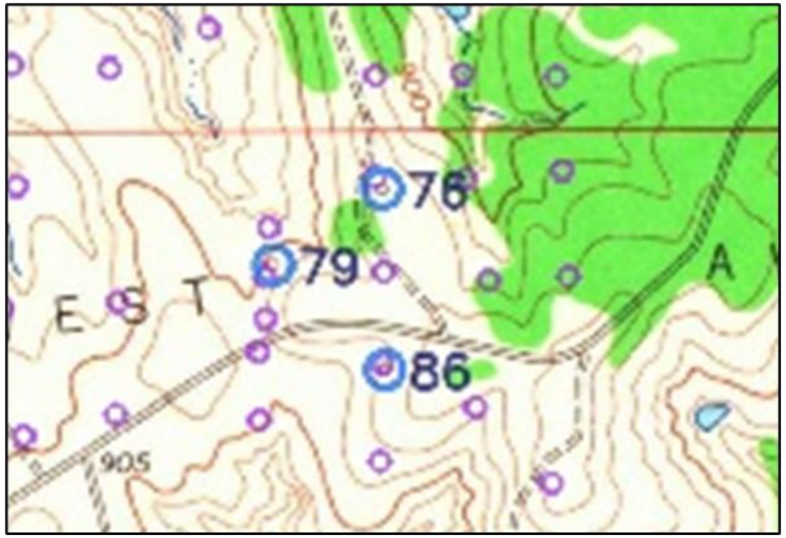
Authority

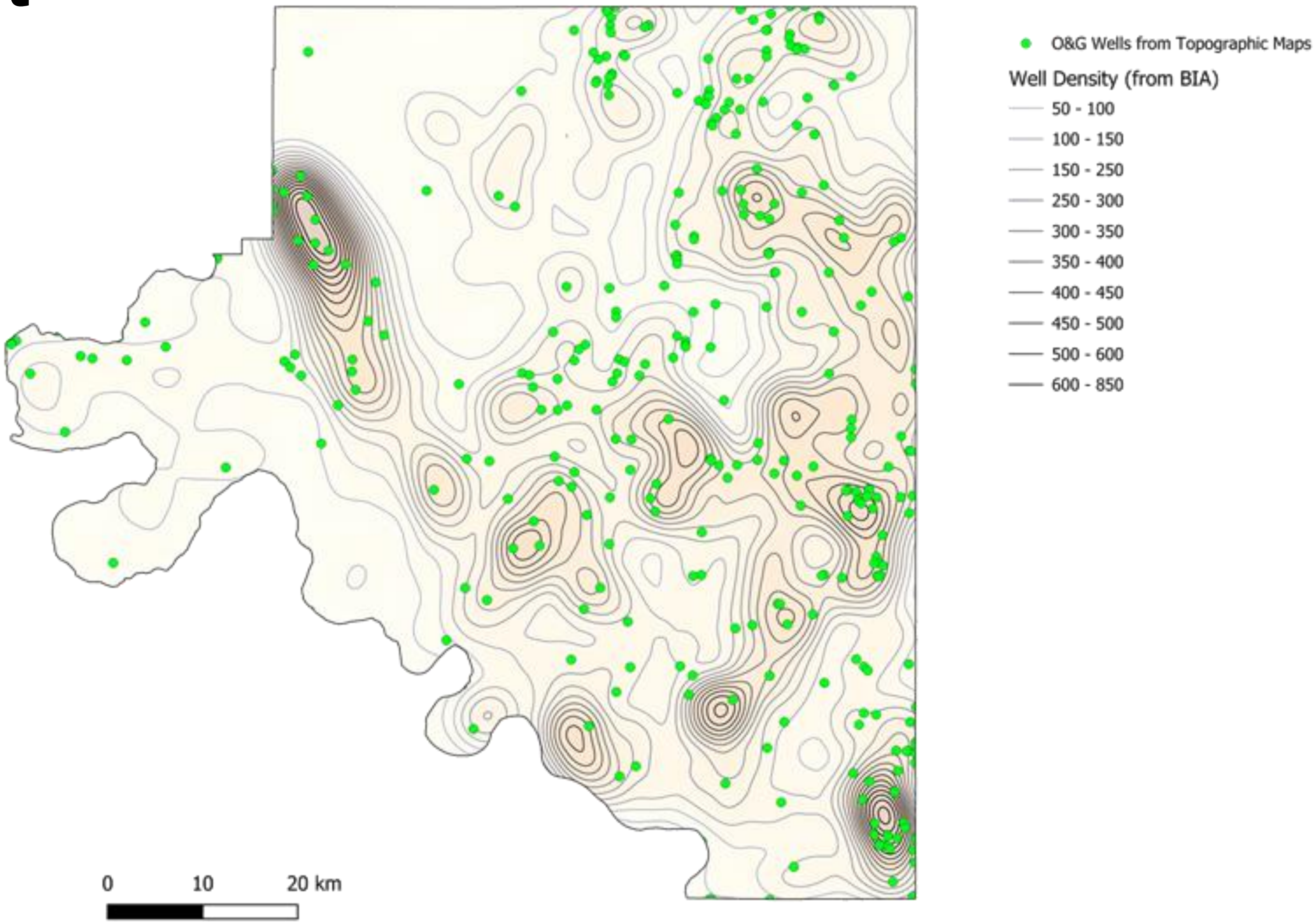
DOE enters into this MOU under the authority of section 646 of the Department of Energy Organization Act (Pub. L. 95-91, as amended; 42 U.S.C. § 7256).

The Osage Nation enters into this MOU under Art. VII, Sec. 1 of the Osage Nation Constitution ratified by the Osage people on March 11, 2006, and signed into law on May 6, 2006.

Pre-field deployment

Image segmentation techniques have been performed on topographic maps covering Osage County to extract O&G well symbology.

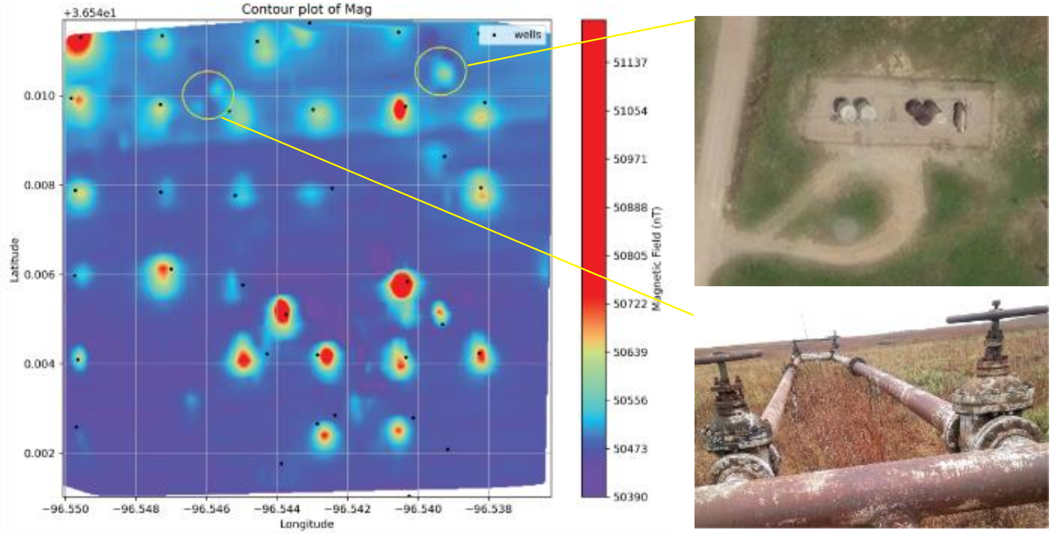




Field deployment

- **Dual airborne sensing:**
  - Aboard a fixed-wing unmanned aerial vehicle.
  - High resolution methane sensor.
  - Magnetometer.
- **Ground-based surveying:**
  - Mobile continuous gas sampling.
  - FLIR camera.
  - Semtech Hi-Flow & FAST.
- **Manned plane sensing:**
  - FARAD PhoeniX X-band radar system
- **Smartphone Geophysics:**
  - Smartphone internal magnetometer, GPS

Fixed-wing UAV equipped with magnetometer and Rotary UAV equipped with wind speed and methane sensor



Example magnetic anomaly map from airborne survey at Osage Nation

Field deployment

- **Dual airborne sensing:**
  - Aboard a fixed-wing unmanned aerial vehicle.
  - High resolution methane sensor.
  - Magnetometer.
- **Ground-based surveying:**
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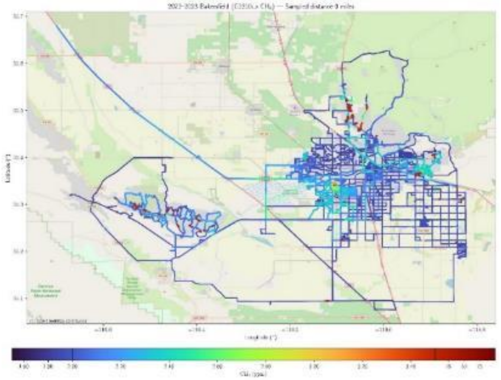

Gas analyzers, sample pump, GPS, 3D wind speed and direction, air temperature & humidity, digital compass

Example of leaking well imaged with FLIR camera

Forced Advection Sampling Technique (FAST) in action

Field deployment

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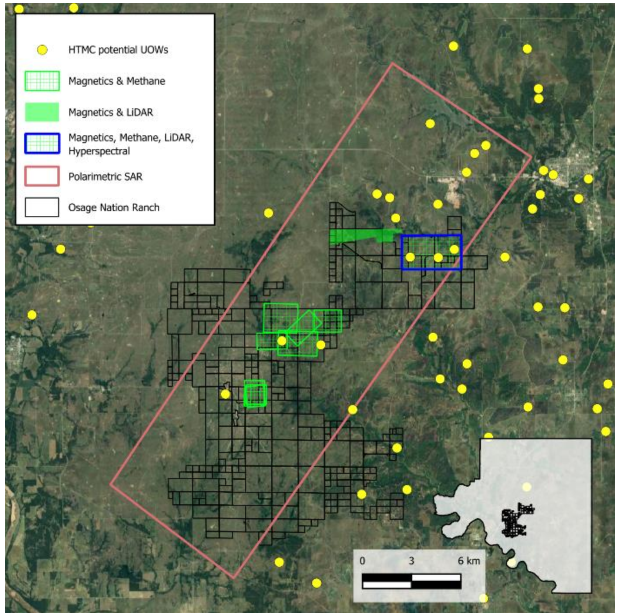
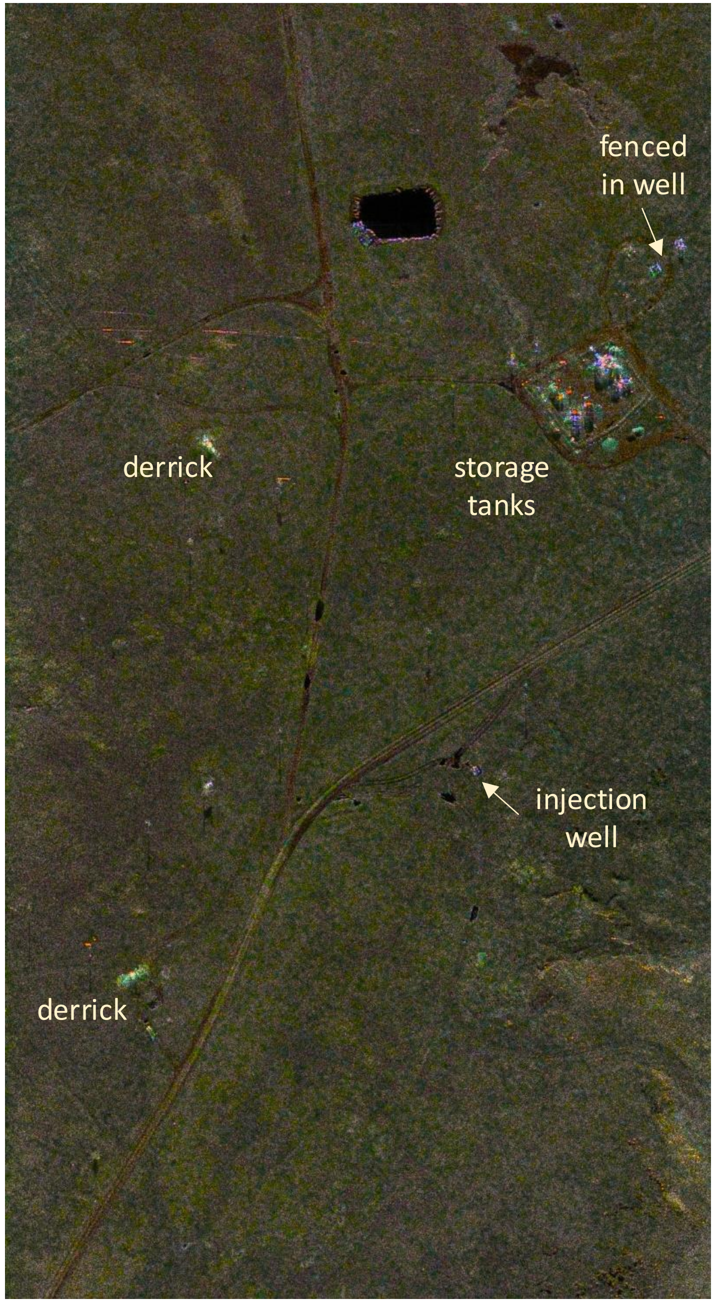
DeHavilland Twin Otter (*NASA.gov*)



PolSAR footprint (pink); UAV footprints (green; HTMC potential UOW (yellow)



Field deployment

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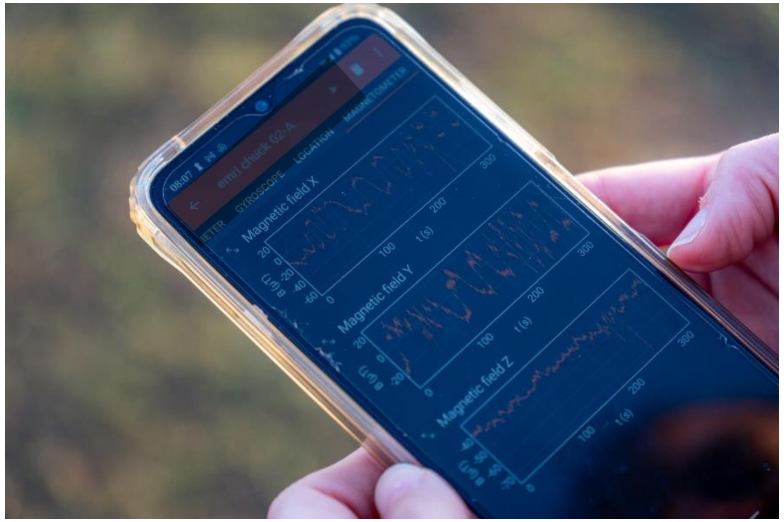
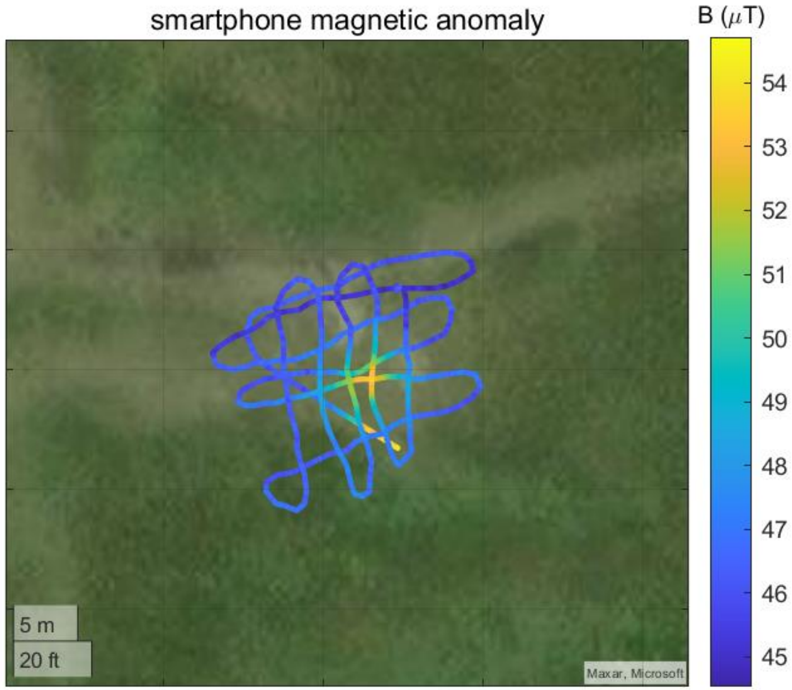




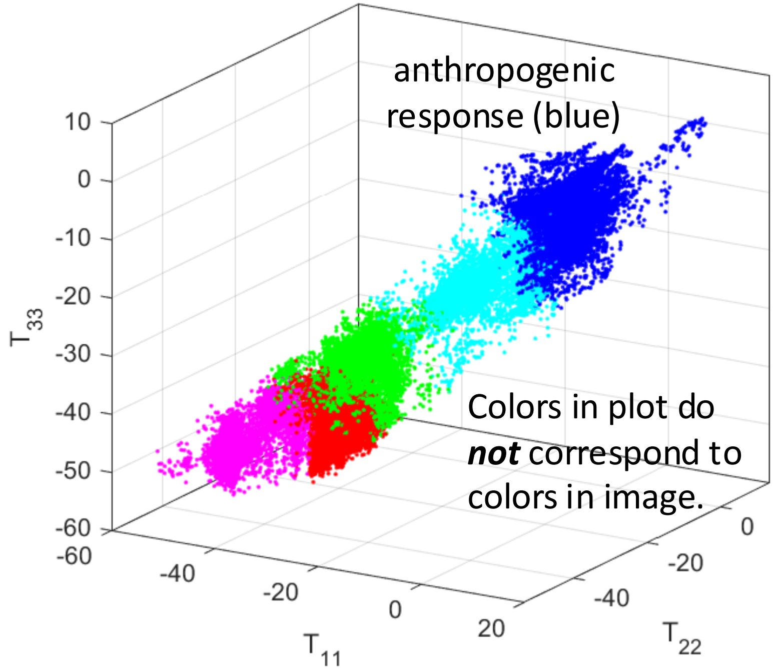
Magnetic anomaly from a buried well.

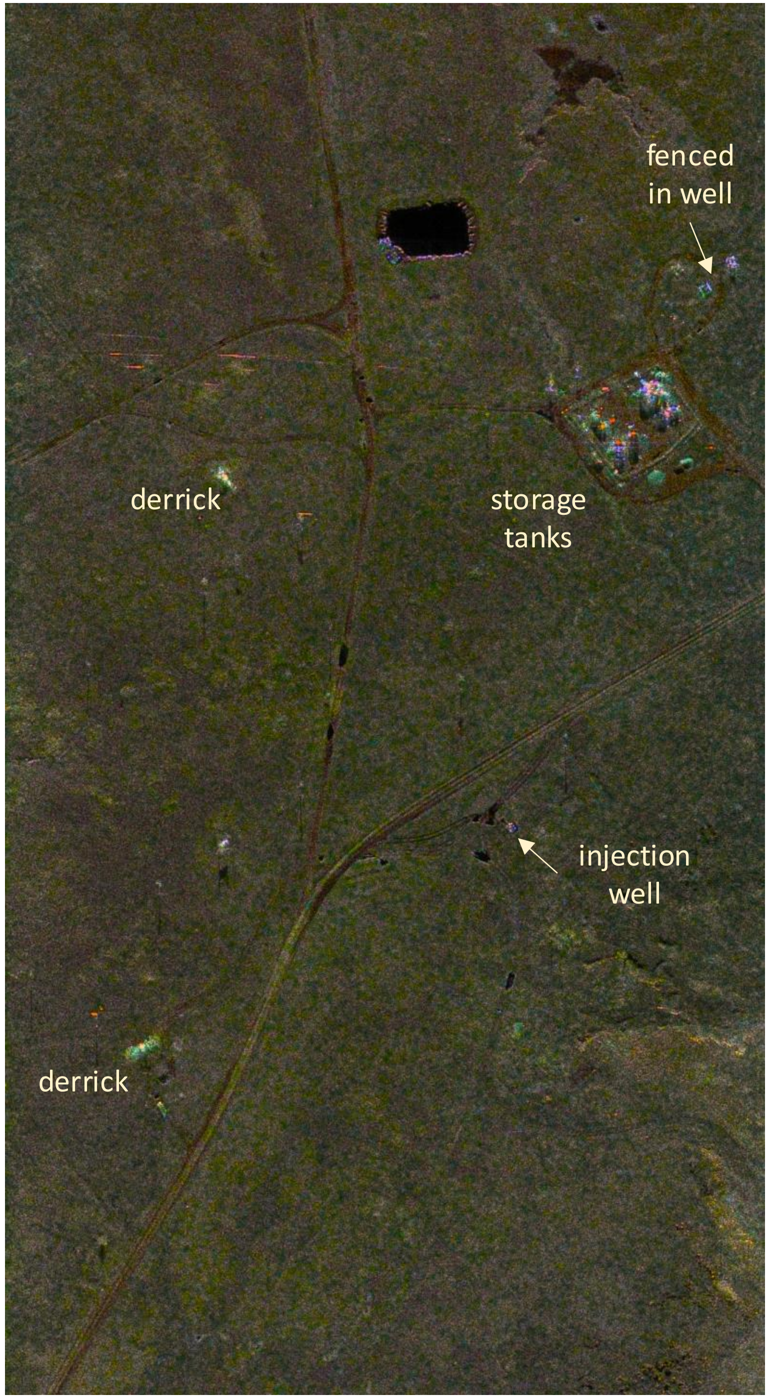
Post-deployment

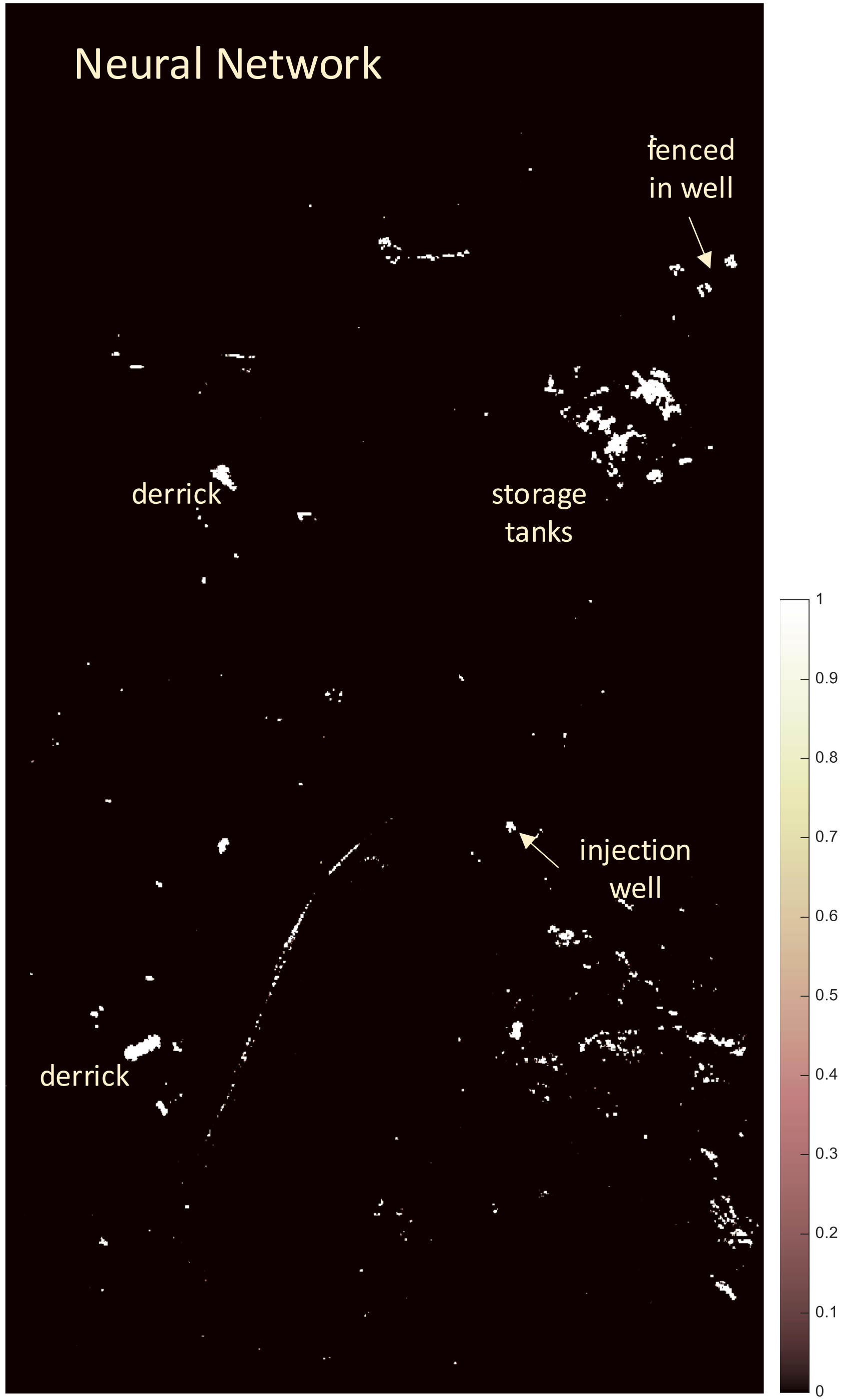
Surface geometries produce different scattering mechanisms:

single surface bounce - double bounce - volumetric - helical

These scattering mechanisms can be grouped and trained to ***classify the response of anthropogenic objects***.







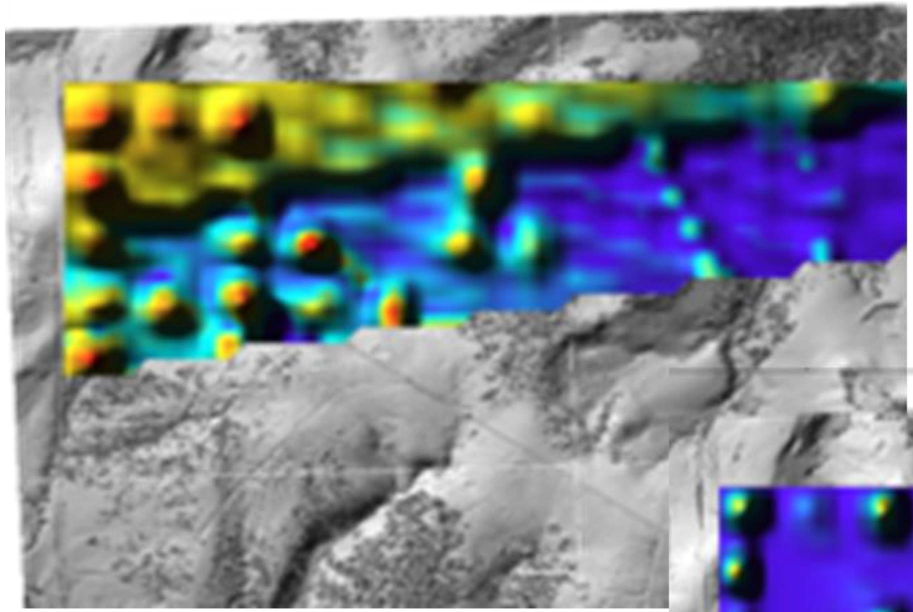
Post-deployment

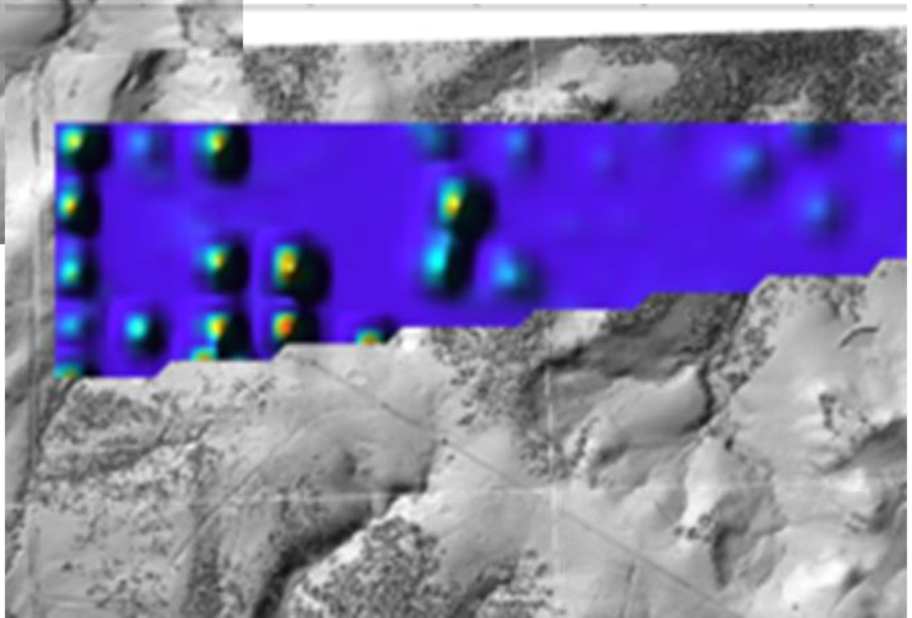
The magnetic anomaly from a vertical cased well is easily distinguishable from other anomalies (i.e., 'bullseye')

Still, post-processing is important:

- *reduction to pole (RTP)*
- *header correction*
- *high & low pass filters*
- *signal decomposition*

RTP example



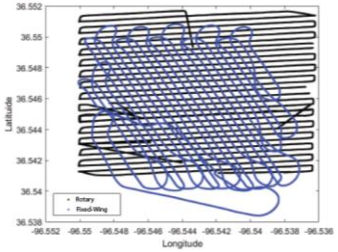


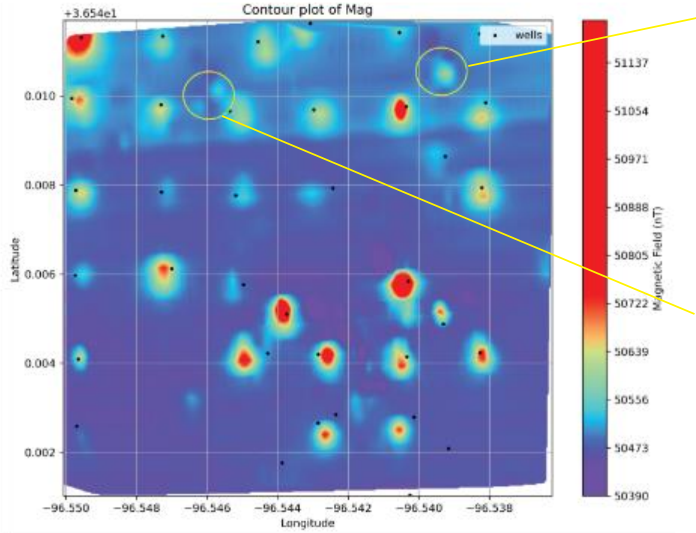
Empirical Mode Decomposition example

Three stages of orphan well remediation

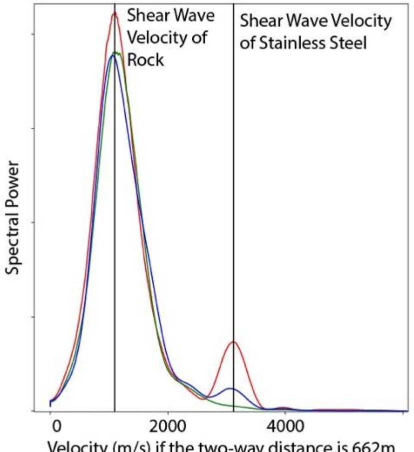
Before going into the field

Finding wells with field work





After finding a well



Conclusions

- Developing methods to attack the orphan well problem at each of the three stages
- Went into some detail on four areas today: topo maps, historical records, quantifying methane emissions, and some of our field work
- We welcome your input and feedback. It has been valuable in guiding our work so far, and we hope to continue that