Consortium Meeting

March 10, 2017

Shelby Peterie
Richard Miller
Dave Newell
Rex Buchanan
Julio Gonzales
John Intfen

Kansas Geological Survey

Tier Structure

Tier 1

Station w/in 15 mi of well(s)

Maintain earthquake catalog and alert members to earthquakes M>2 within 30 miles of well(s)

Quarterly reports

Annual reports (unrestricted use)

Participate in annual meetings

Voting rights
- Priorities
- Focus Areas

Tier 2

Annual reports—*internal use*

Participate in annual meetings, discussions and data review

Might deploy temporary station(s) to investigate seismicity in proximity to company wells

KDHE

Invited to attend annual meetings

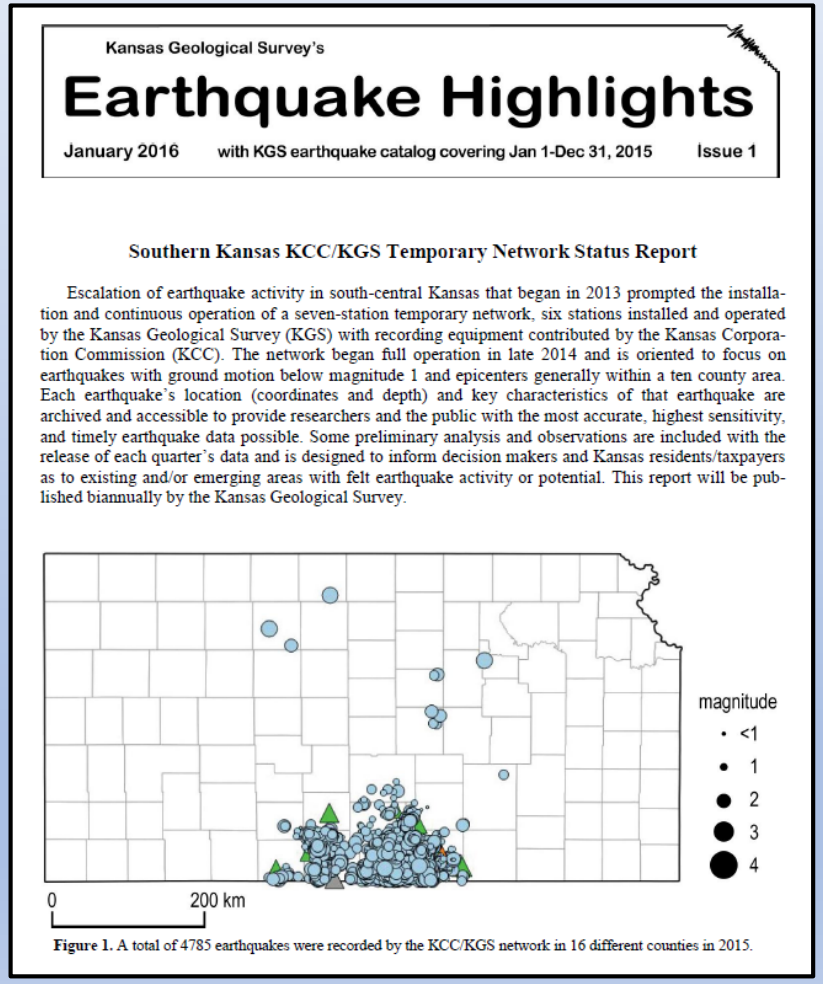
DRAFT annual report (limits use and distribution to 6 months)

Downstream Data Applications & Research Products

Summary of Potential Products

Reports
- Catalog
- Focus areas
  - Epicenter maps
  - Regional injection
- Individual wells (15mi)
  - Epicentral distance maps
  - Injection & micro-earthquakes
- Synthesis & Discussion

Website
- Earthquake Mapper
- Live feeds
- Blog



Kansas Geological Survey's

Earthquake Highlights

January 2016 with KGS earthquake catalog covering Jan 1-Dec 31, 2015 Issue 1

Southern Kansas KCC/KGS Temporary Network Status Report

Escalation of earthquake activity in south-central Kansas that began in 2013 prompted the installation and continuous operation of a seven-station temporary network, six stations installed and operated by the Kansas Geological Survey (KGS) with recording equipment contributed by the Kansas Corporation Commission (KCC). The network began full operation in late 2014 and is oriented to focus on earthquakes with ground motion below magnitude 1 and epicenters generally within a ten county area. Each earthquake's location (coordinates and depth) and key characteristics of that earthquake are archived and accessible to provide researchers and the public with the most accurate, highest sensitivity, and timely earthquake data possible. Some preliminary analysis and observations are included with the release of each quarter's data and is designed to inform decision makers and Kansas residents/taxpayers as to existing and/or emerging areas with felt earthquake activity or potential. This report will be published biannually by the Kansas Geological Survey.

Figure 1. A total of 4785 earthquakes were recorded by the KCC/KGS network in 16 different counties in 2015.

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date	time	latitude	longitude	magnitude
2015-01-01	14:41:48	37.254	-98.018	1.8
2015-01-01	15:17:38	37.246	-98.001	2.4
2015-01-01	15:41:25	37.250	-98.030	1.9
2015-01-01	15:47:31	37.263	-98.031	2.3
2015-01-02	00:03:38	37.256	-98.029	2.4
2015-01-02	00:08:01	37.071	-97.708	2.1
2015-01-02	00:26:37	37.273	-98.005	1.8
2015-01-02	04:55:17	37.155	-97.890	1.8
2015-01-02	06:35:39	37.079	-97.715	2.3
2015-01-02	08:28:02	37.201	-97.891	2.3
2015-01-02	08:37:36	37.090	-97.708	2.2
2015-01-02	08:51:11	37.201	-97.890	1.6
2015-01-02	10:40:10	37.249	-97.959	1.7
2015-01-02	11:53:28	37.194	-97.892	1.8
2015-01-02	12:34:20	37.198	-97.897	2.1
2015-01-02	12:45:37	37.247	-98.034	1.7
2015-01-02	13:08:51	37.236	-98.010	2.0
2015-01-02	13:32:55	37.222	-97.877	2.1
2015-01-02	14:03:42	37.201	-97.889	2.1
2015-01-02	15:22:24	37.208	-97.881	1.6
2015-01-02	17:02:13	37.253	-98.027	1.4
2015-01-02	17:55:46	37.195	-97.892	1.4
2015-01-02	18:25:55	37.249	-98.035	1.6
2015-01-02	23:17:15	37.230	-98.037	1.7
2015-01-03	05:33:19	37.101	-97.999	2.4
2015-01-03	08:17:08	37.064	-97.717	1.9
2015-01-03	11:30:17	37.193	-98.029	1.6
2015-01-03	17:56:46	37.275	-97.610	1.3
2015-01-03	19:12:26	37.098	-97.690	1.5
2015-01-03	20:10:51	37.194	-97.911	1.9
2015-01-03	20:16:51	37.198	-97.894	1.8
2015-01-03	21:18:45	37.155	-97.988	1.9
2015-01-04	00:37:36	37.187	-97.897	1.8
2015-01-04	09:35:09	37.276	-98.001	1.5
2015-01-04	10:44:08	37.243	-98.027	2.2
2015-01-04	10:55:47	37.266	-98.029	2.5
2015-01-04	11:20:28	37.244	-98.052	2.2

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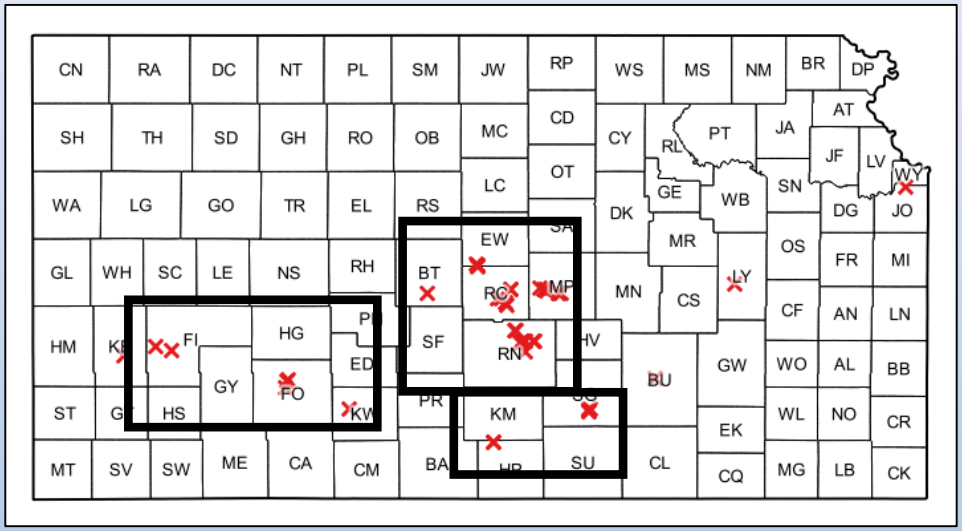

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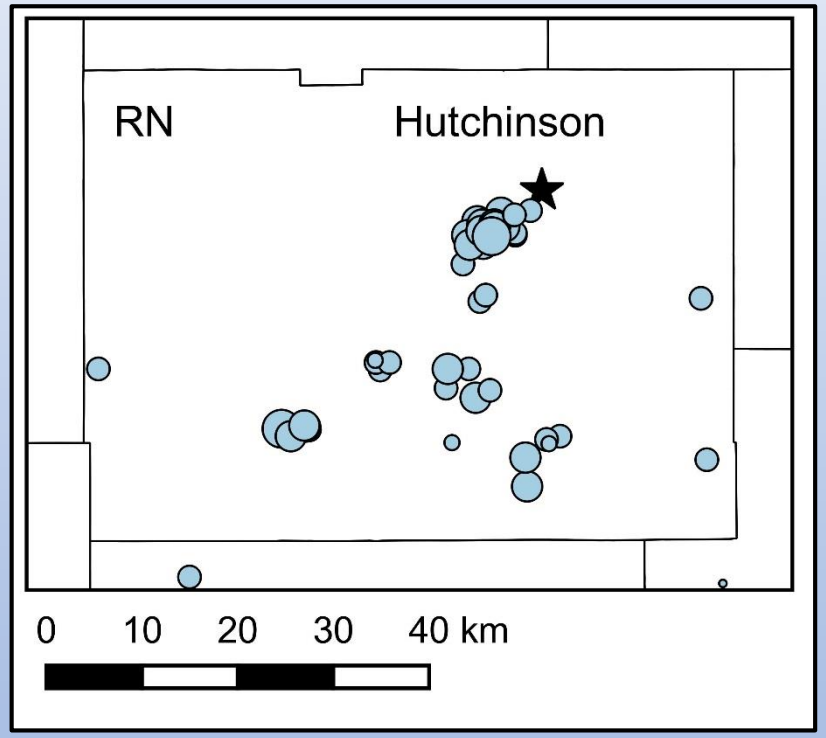

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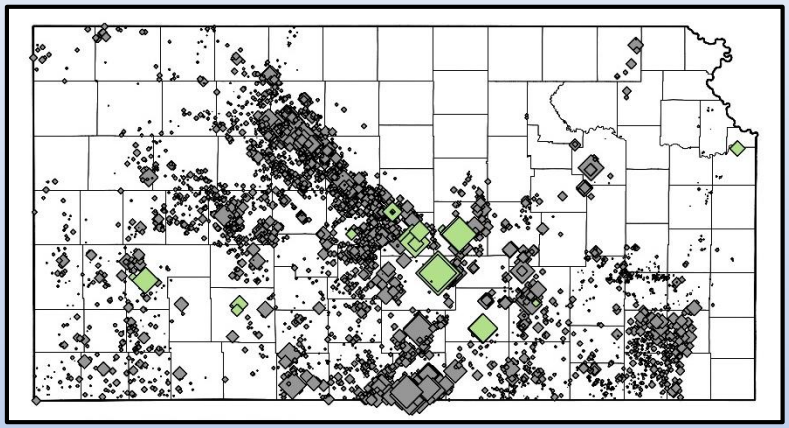

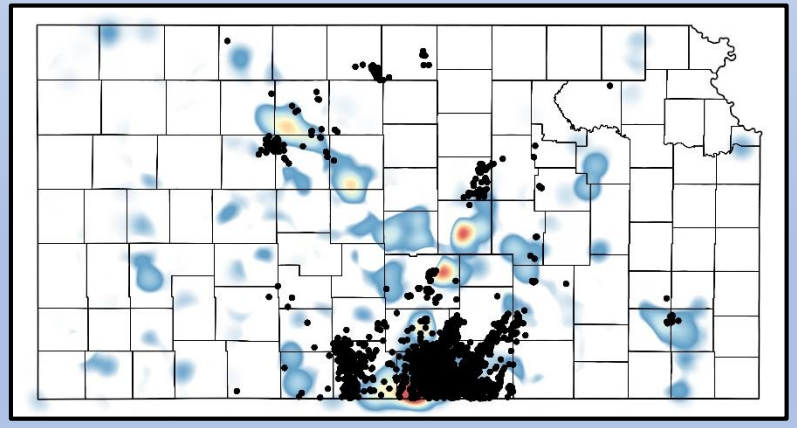

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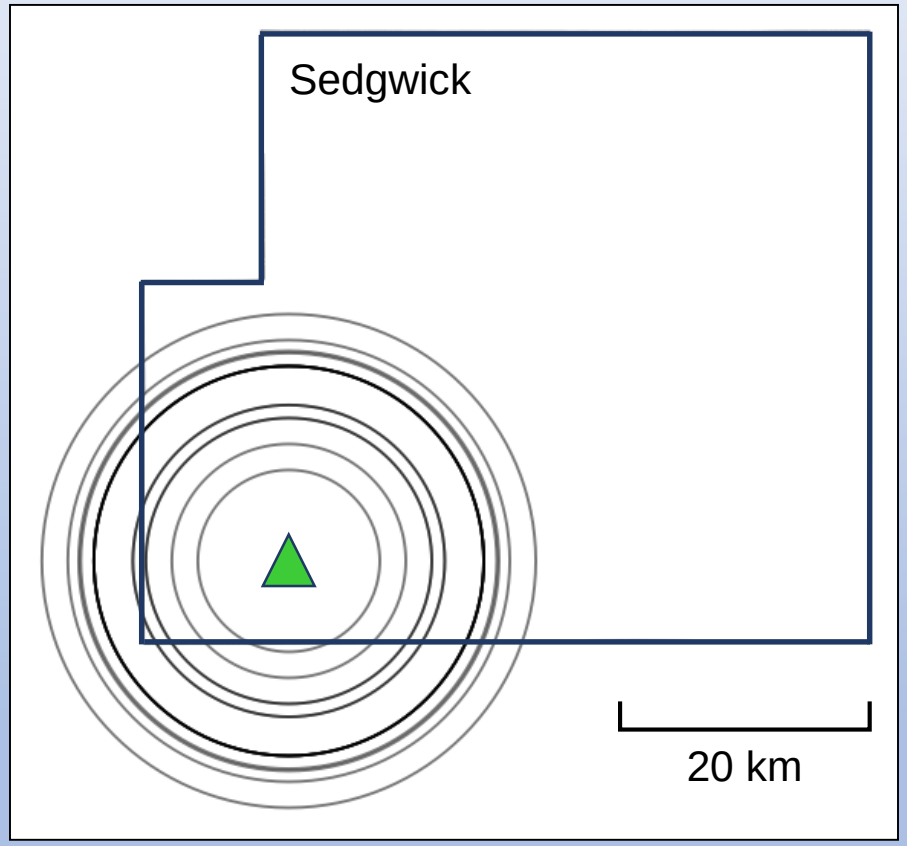

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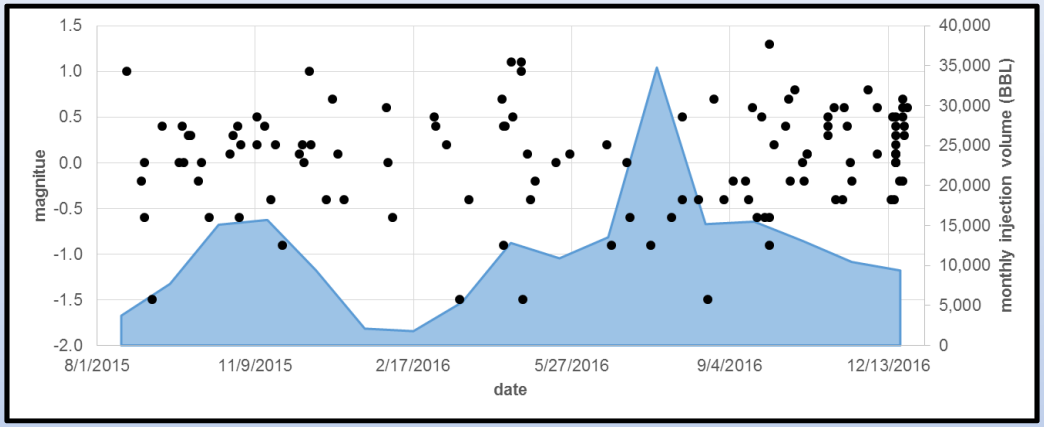

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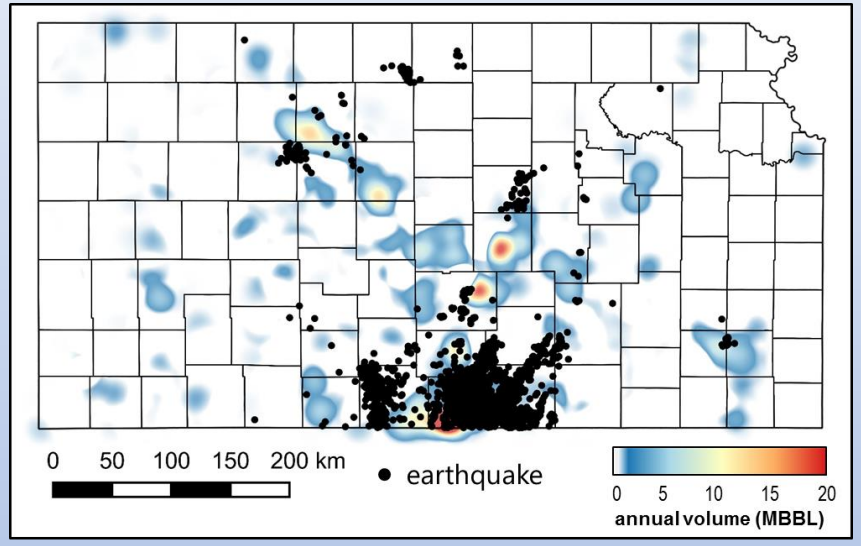

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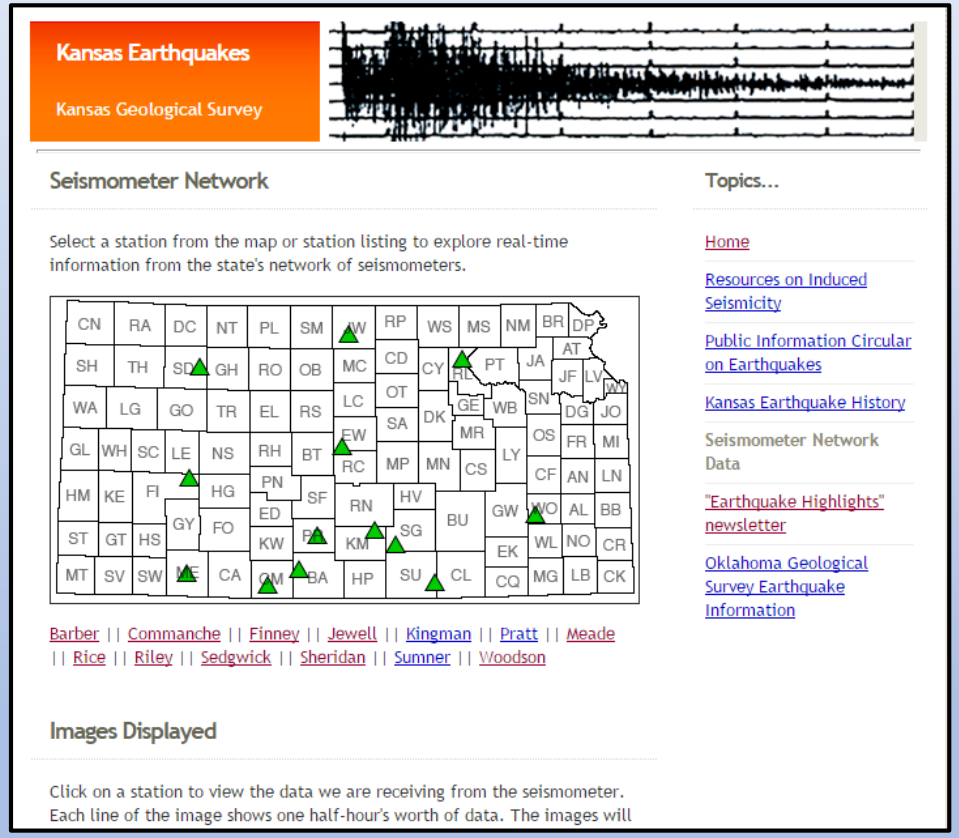

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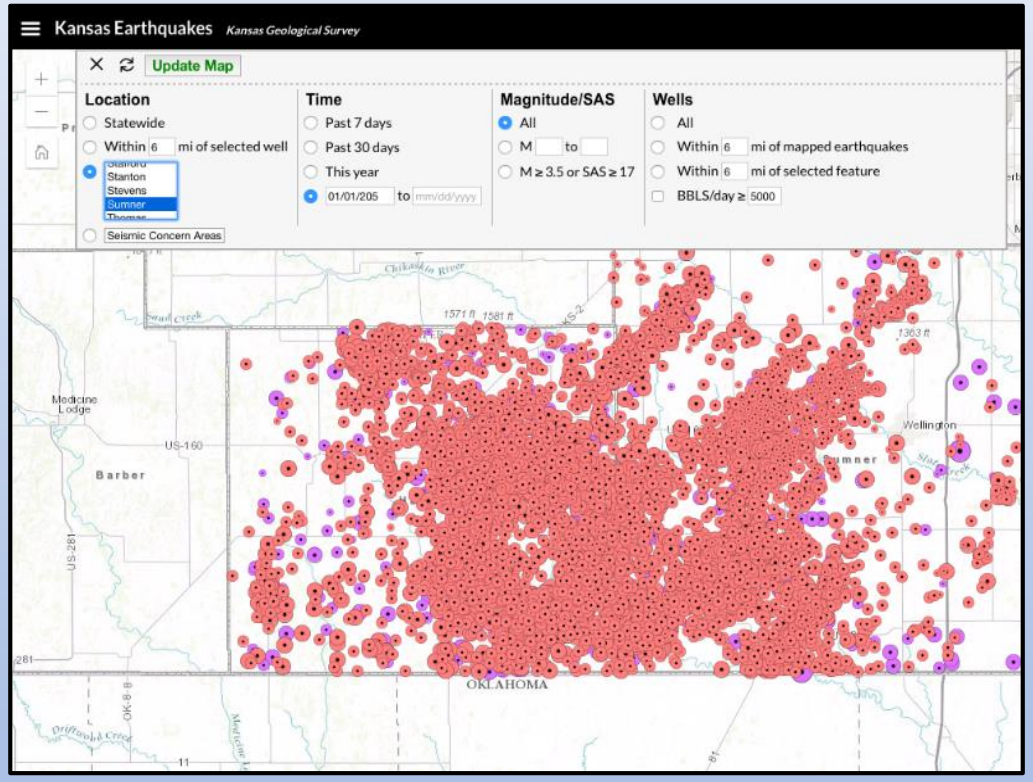

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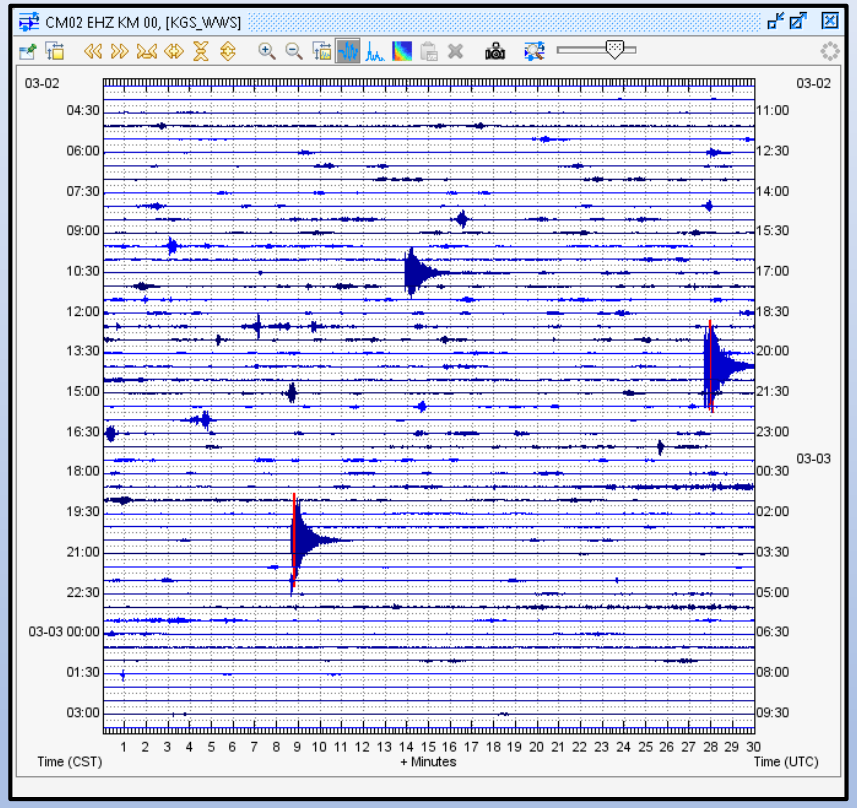

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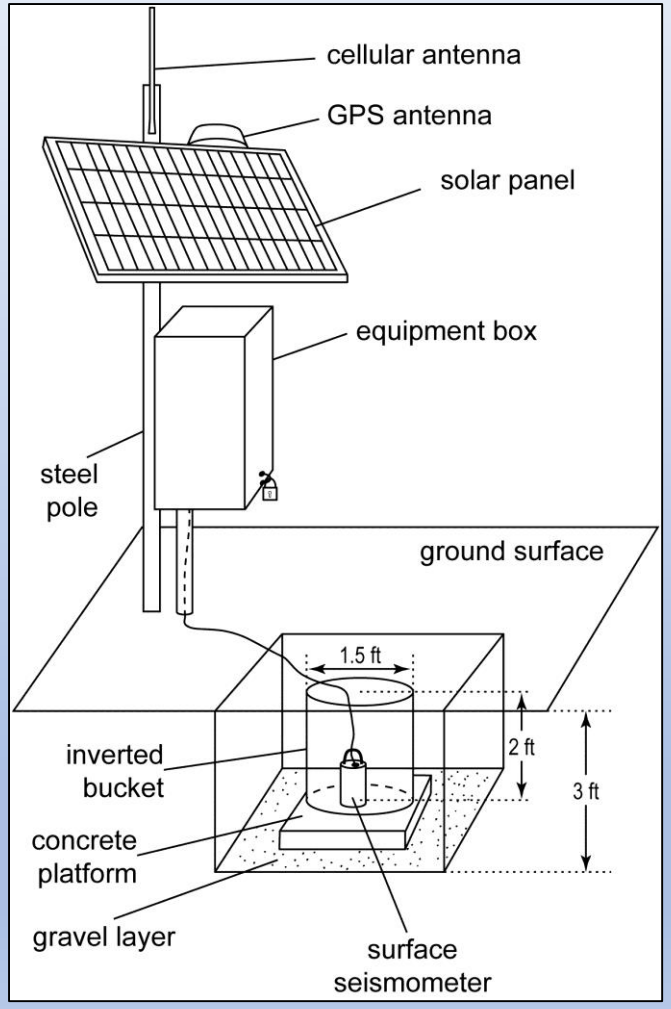
Equipment and Budget

Seismic Station

Seismic sensor
- Seismometer
- Digitizer

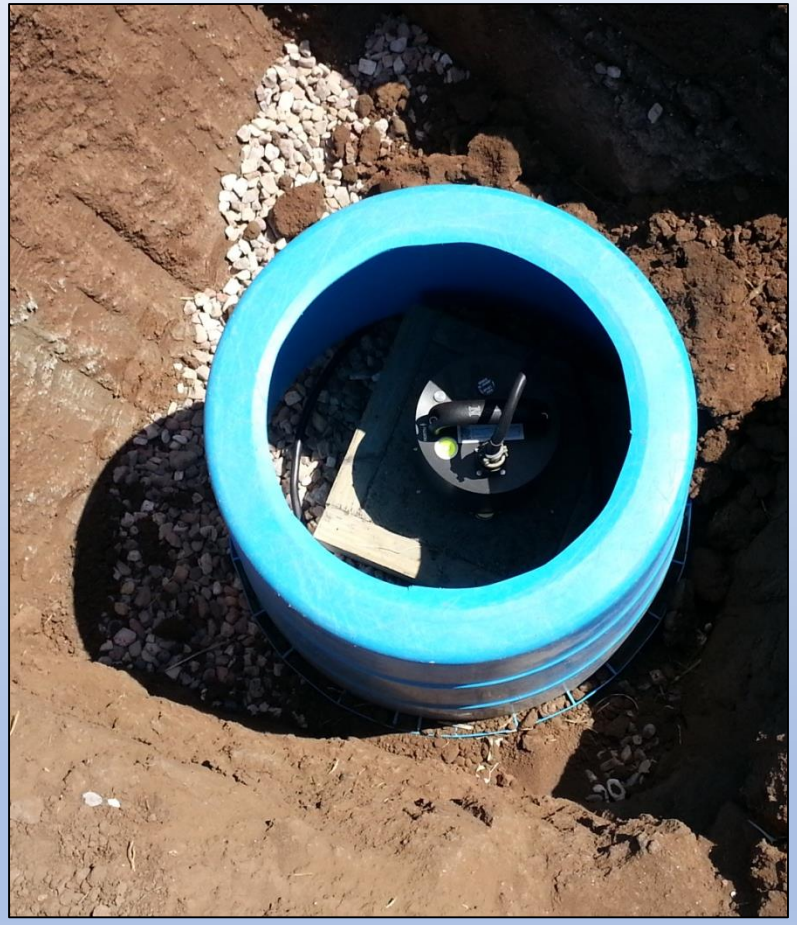
Real-time communications
- cellular modem
- cellular antenna
- RTP server

Power
- 120 watt 12 V solar panel
- charge controller
- two deep-cycle marine batteries



Seismic Station Installation

Seismic Station Installation



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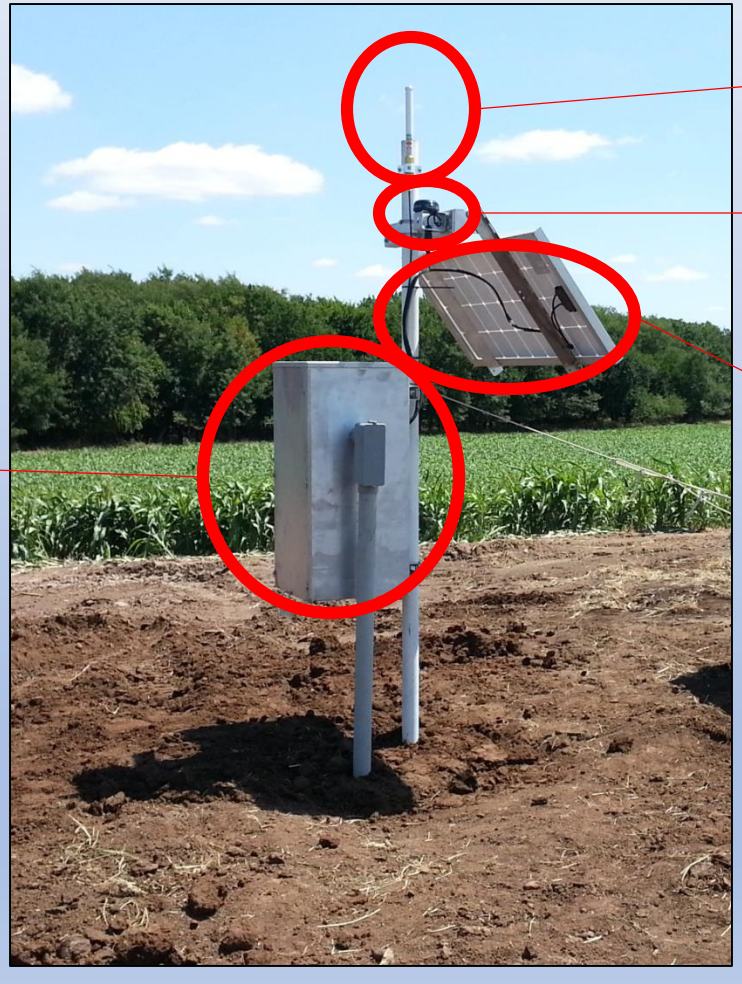


Seismic Station Installation

Seismic Station Installation

charge controller

cell modem

digitizer

batteries

Annual Cost

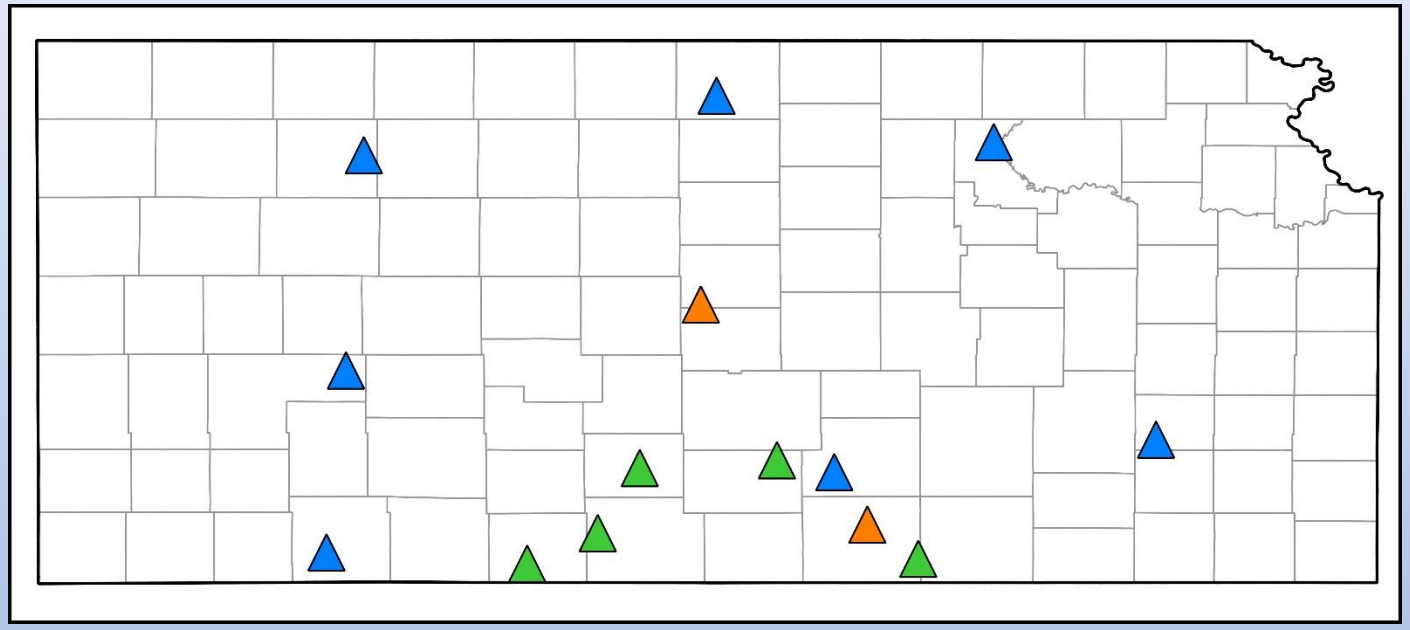
Item	Tier 1 annual cost	Tier 2 annual cost
Access to Annual Report		$ 5,000
telemetry	$ 500	
annual maintenance	$ 1,000	
analyst	$ 2,500	
total	***$ 4,000***	***$ 5,000***

Single Station Cost

item	one-time cost
seismometer and sensor cable	$ 5,000
digitizer	$ 6,000
cell modem, antenna, cable	$ 1,000
Solar panel, mounting bracket, batteries, charge controller, wiring	$ 1,500
GPS antenna and cable	$ 500
enclosure, conduit, concrete, pole, gravel	$ 1,000
installation	$ 2,000
total	***$ 17,000***

Network Design and Site Selection

Current KGS Network

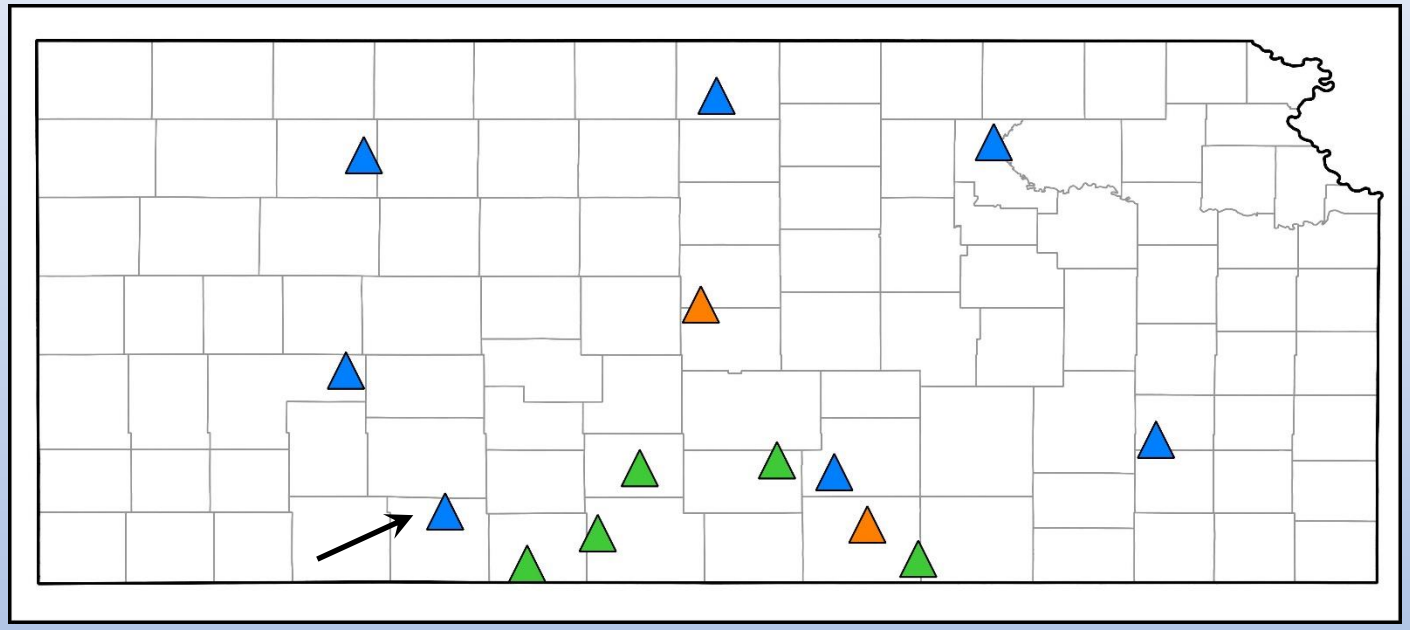


KGS/KCC temporary station

KGS permanent station

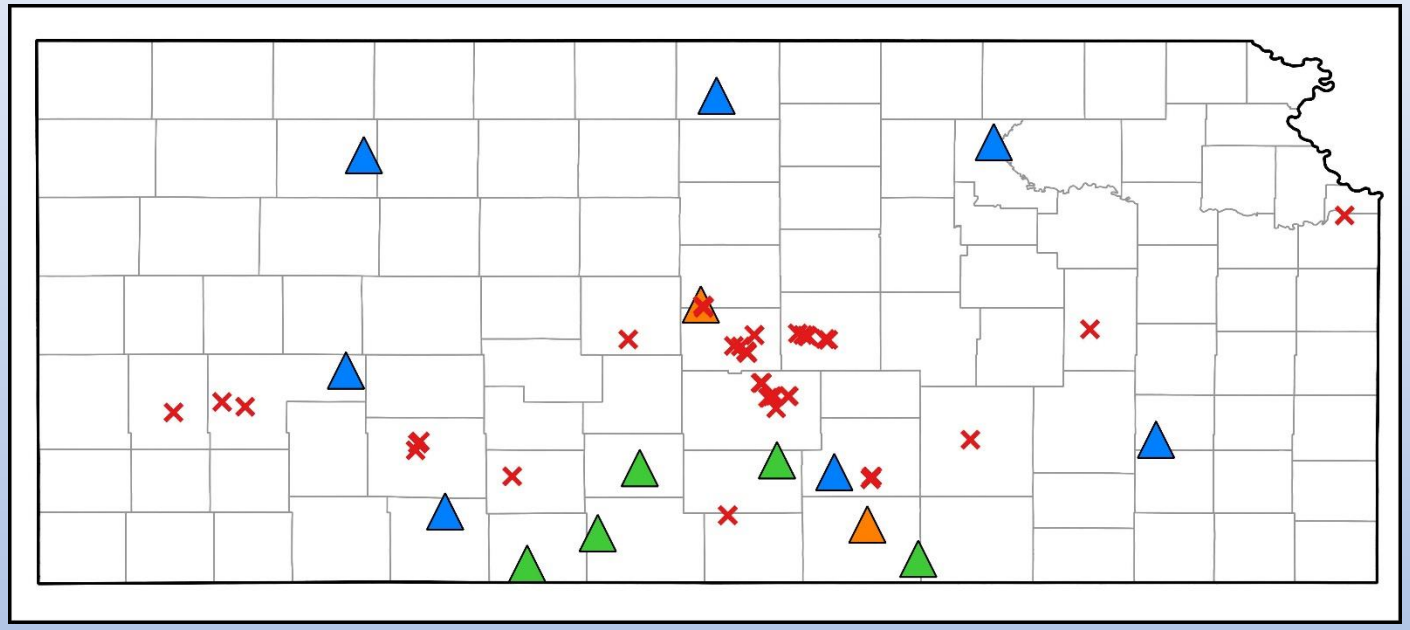
Other KGS temporary station

Current KGS Network



KGS permanent station
KGS/KCC temporary station
Other KGS temporary station

Current Sensitivity Around Class I Wells

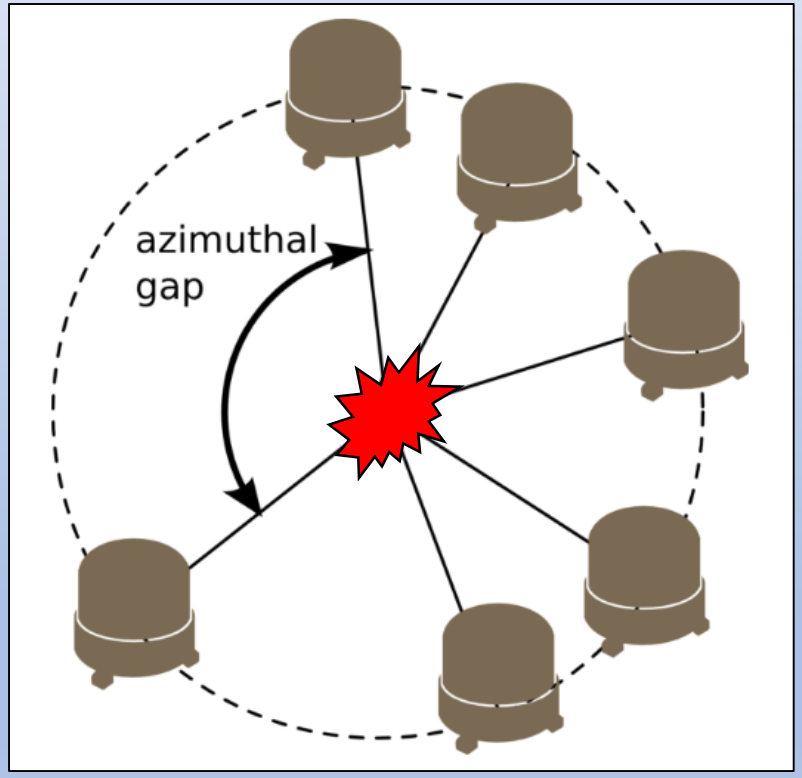


KGS permanent station
KGS/KCC temporary station
Other KGS temporary station
X class I well

Principles of Network Design: Gap

Definition: The largest azimuthal gap between azimuthally adjacent stations (in degrees)

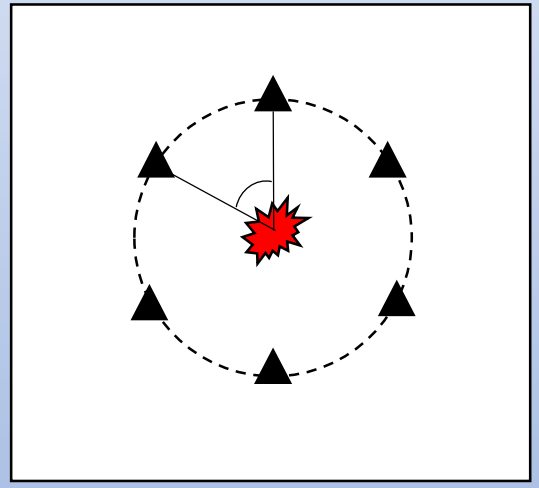
theoretical network (map view)



Principles of Network Design: Gap

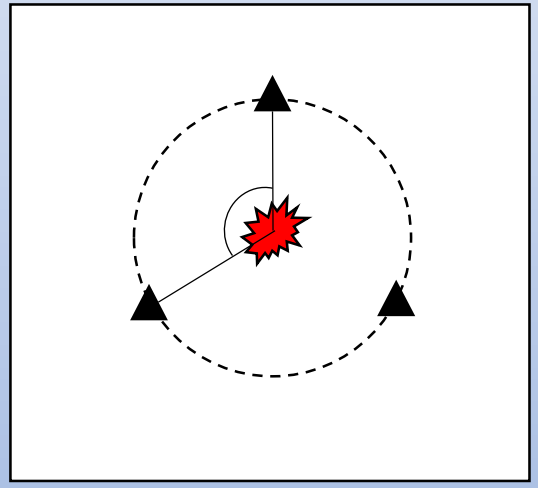
Definition: The largest azimuthal gap between azimuthally adjacent stations (in degrees)

dense network



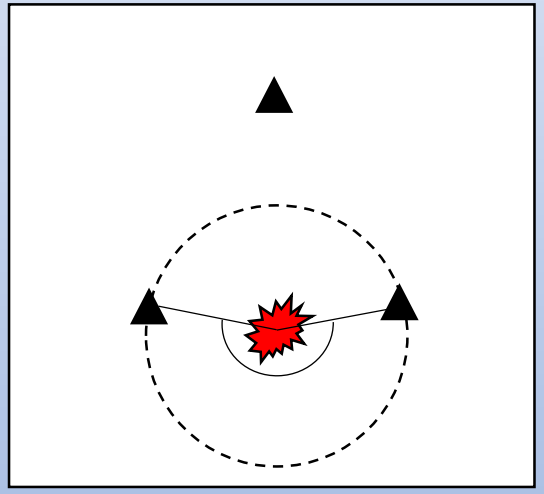
small gap
excellent accuracy

sparse network



large gap
good accuracy

sparse network

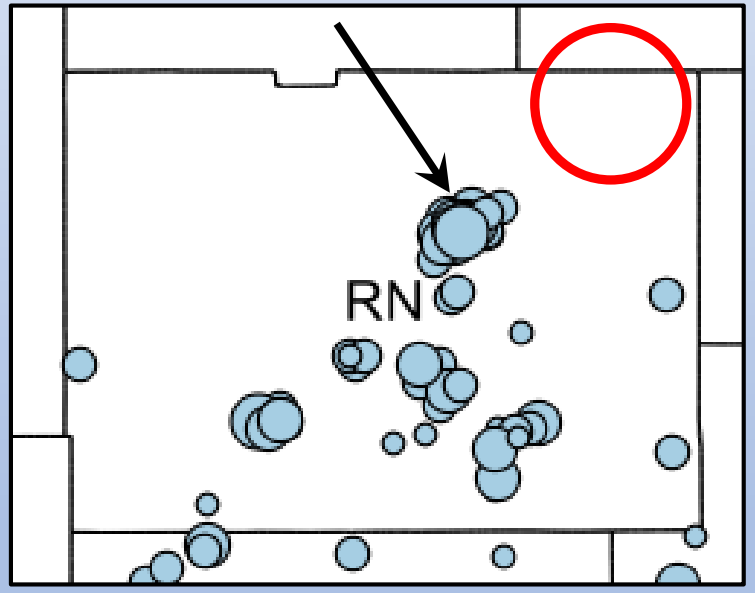


very large gap
large uncertainty

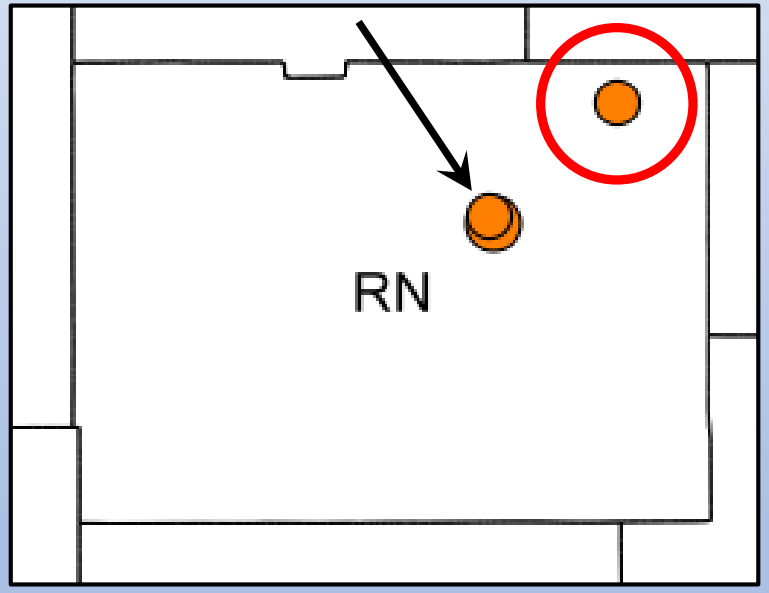
Importance of Azimuthal Gap

location error

KGS



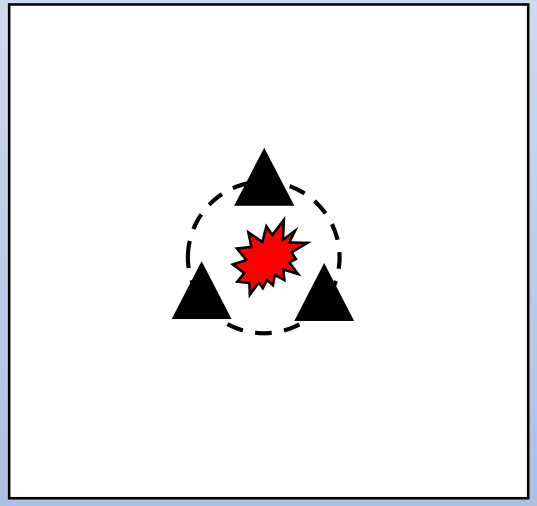
USGS



Principles of Network Design: Sensitivity

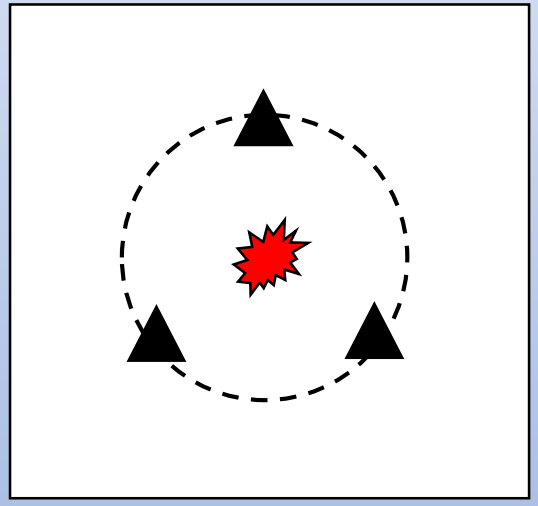
Definition: Minimum detectable magnitude (≥3 stations)

very close stations



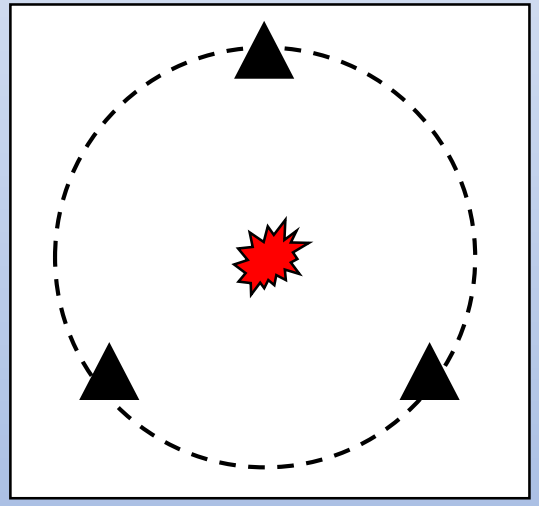
M 1

close stations



M 2

distant stations

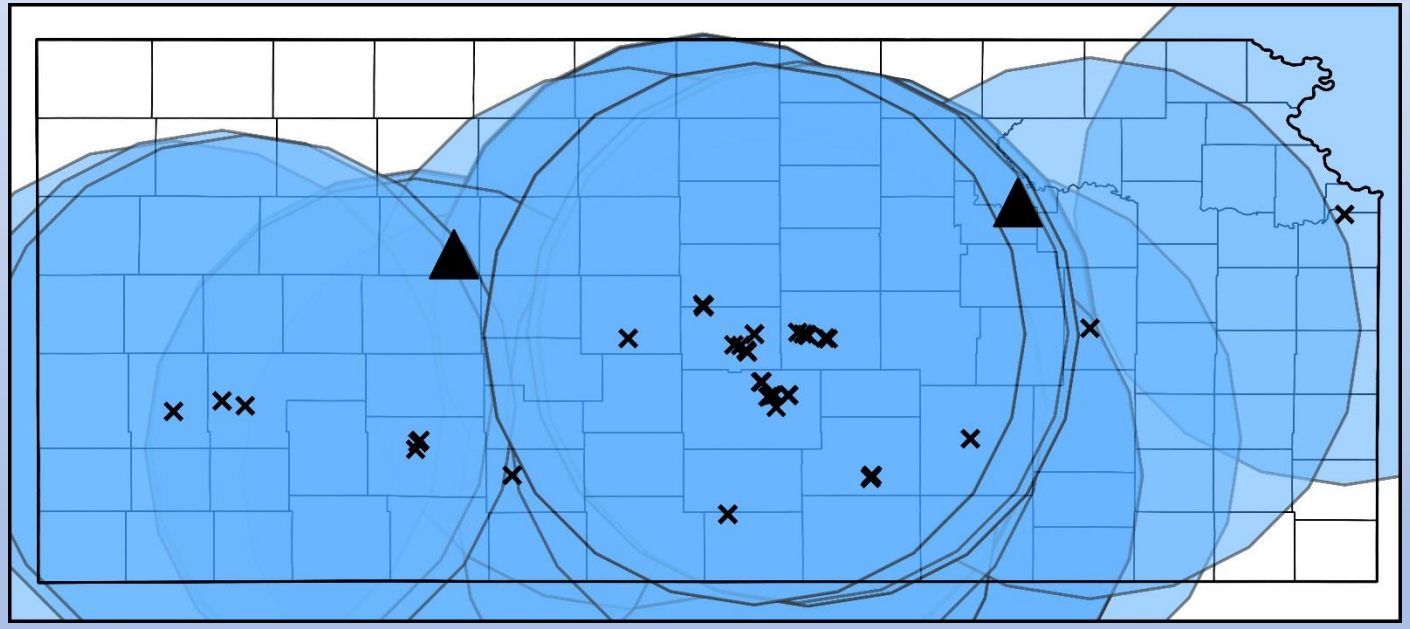


M 3

USGS Network Sensitivity

M 2–2.5 (150 km)

radius around all class I wells, must have 3 stations to locate



X class I well

▲ seismic station

KGS Network Sensitivity

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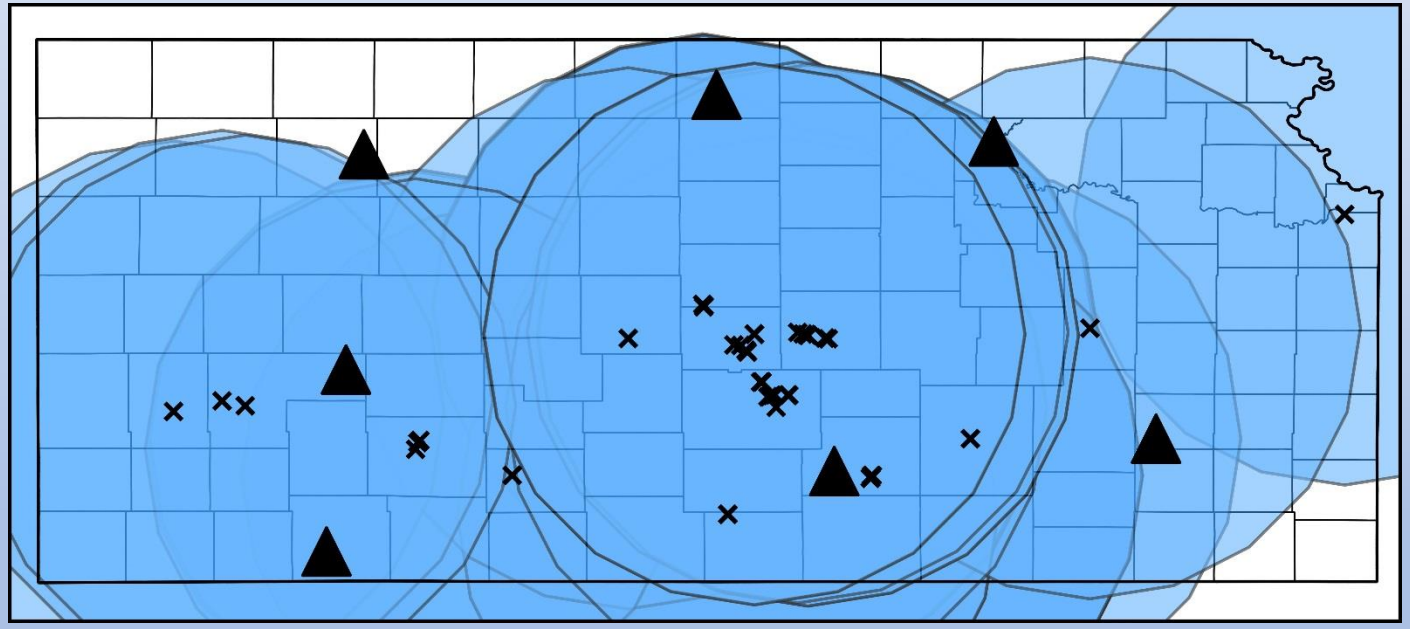
radius around all class I wells, must have 3 stations to locate



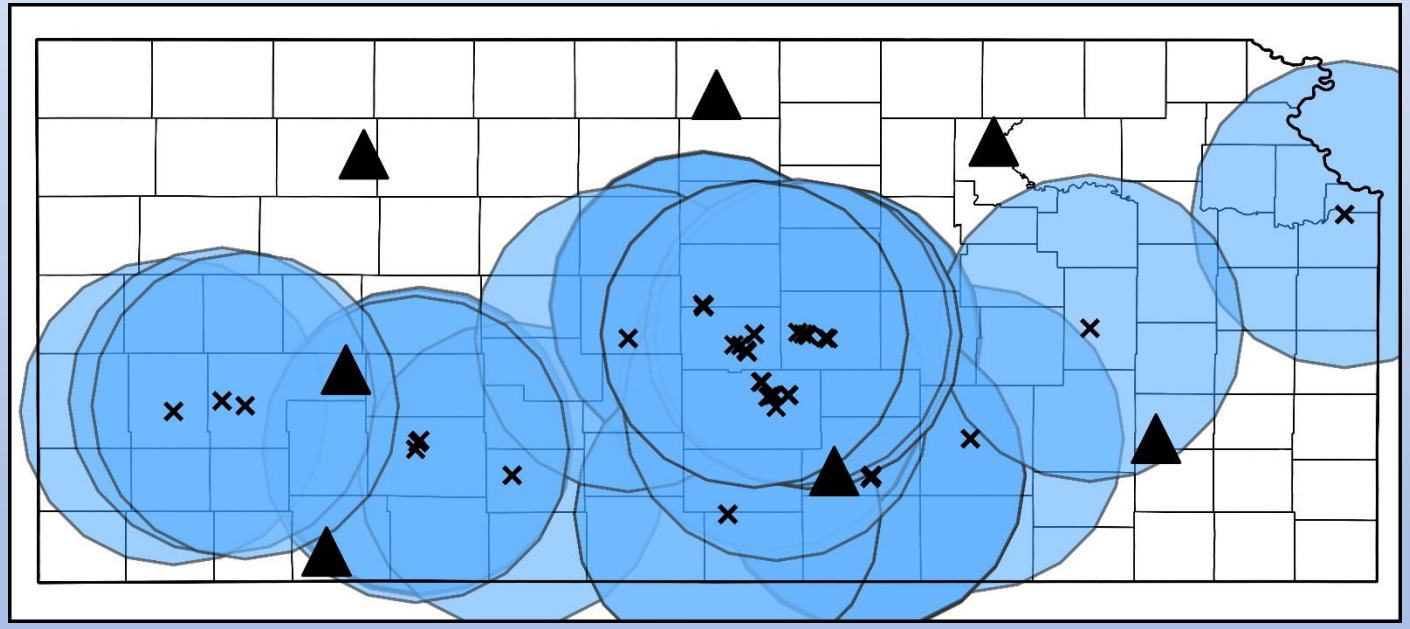
X class I well

▲ seismic station

KGS Network Sensitivity

M 1.5-2 (85 km)

radius around all class I wells, must have 3 stations to locate



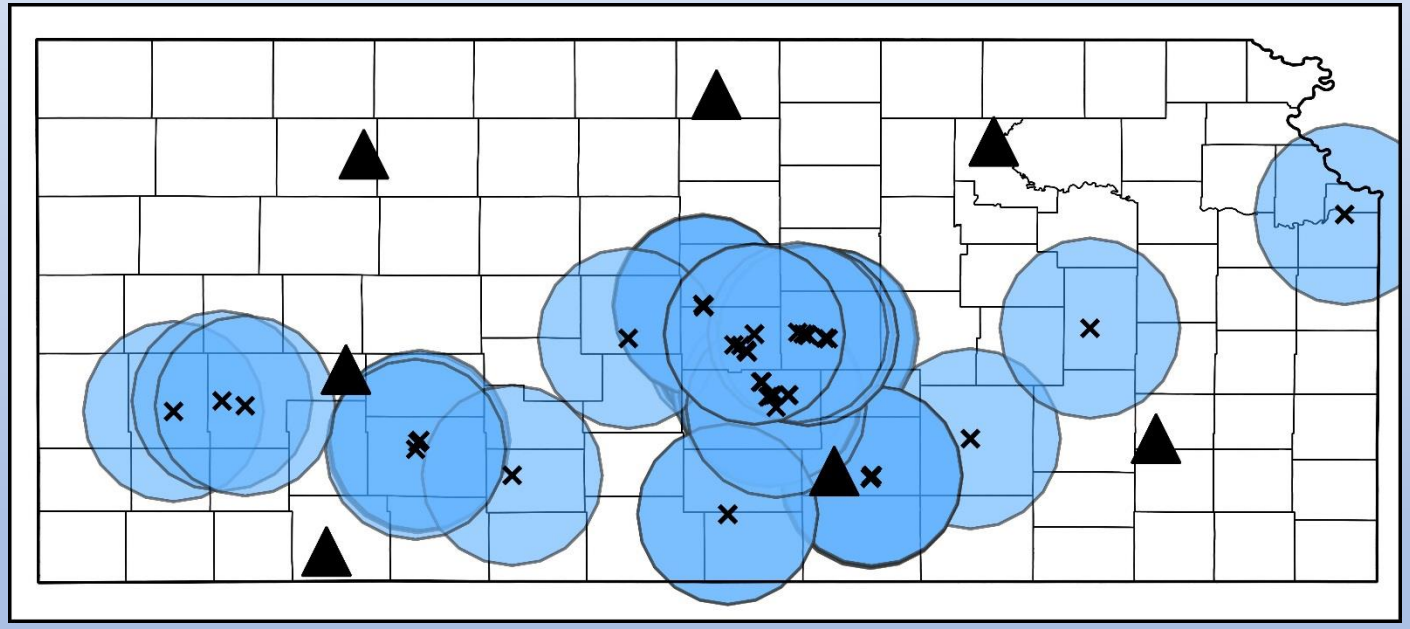
X class I well

▲ seismic station

KGS Network Sensitivity

M 1-1.5 (50 km)

radius around all class I wells, must have 3 stations to locate



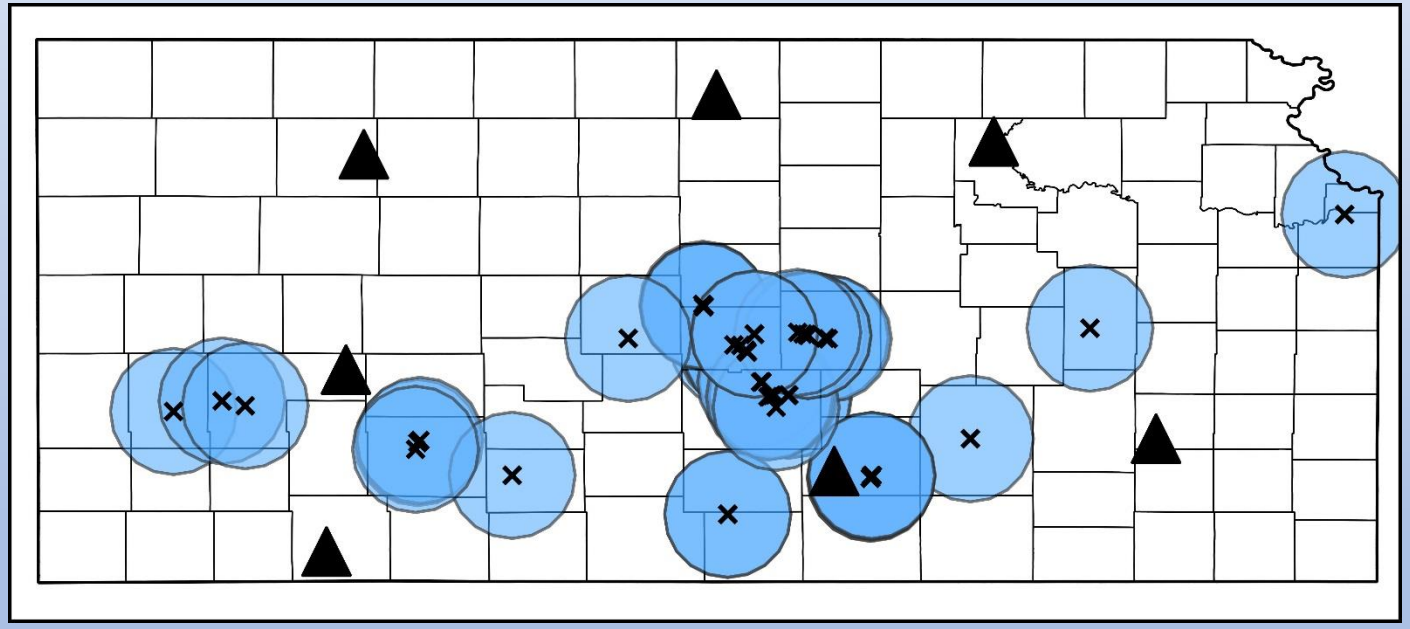
X class I well

▲ seismic station

KGS Network Sensitivity

M 0.5-1 (35 km)

radius around all class I wells, must have 3 stations to locate

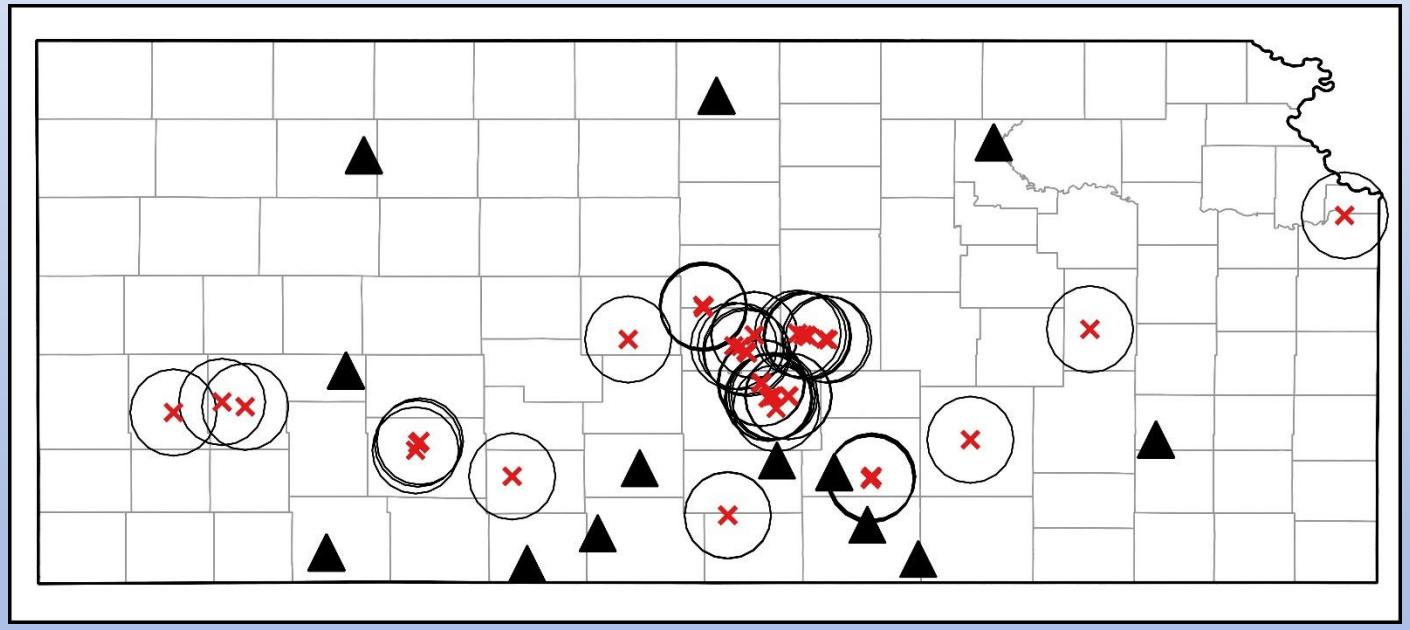


X class I well

▲ seismic station

Consortium Network Design

stations located within 15 mi radius from class I wells



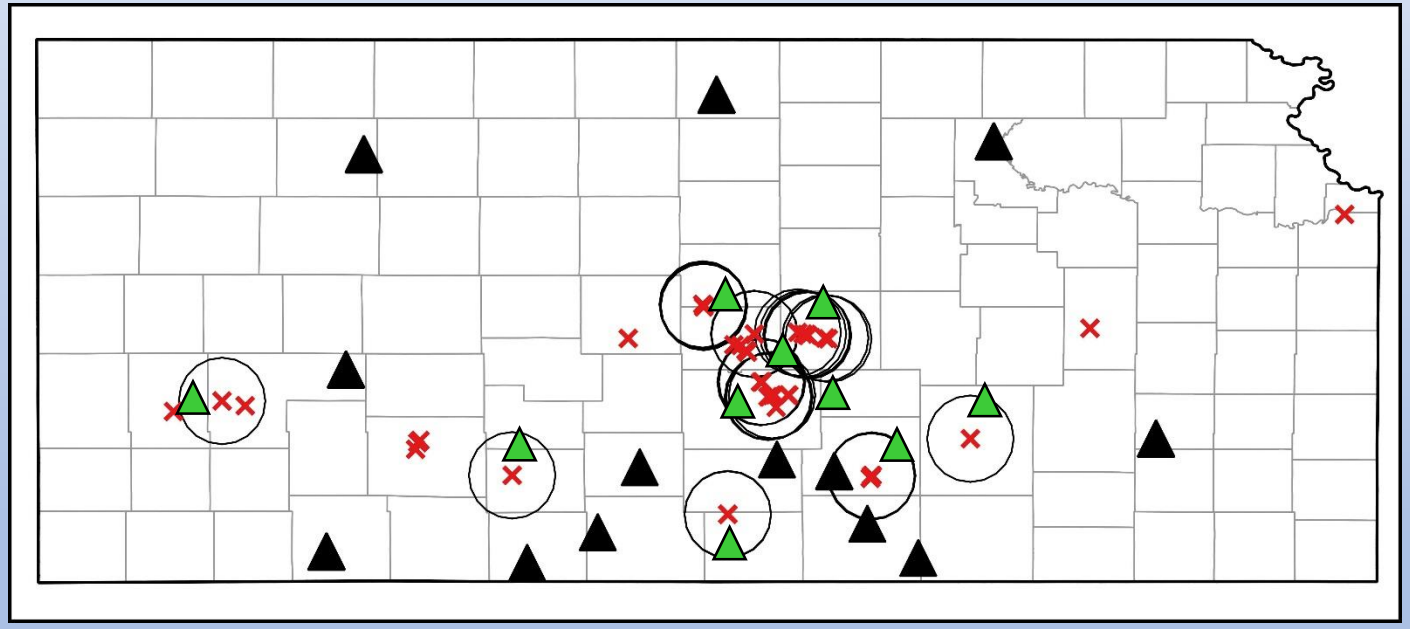
X class I well

▲ KGS seismic station

◯ 15 mi radius

Minimum Member Design

member	Holly Frontier	CHS	Northern Natural Gas	ONEOK	OXY Chemicals	Tyson
# of stations	1	1	2	2	1	1



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▲ KGS seismic station

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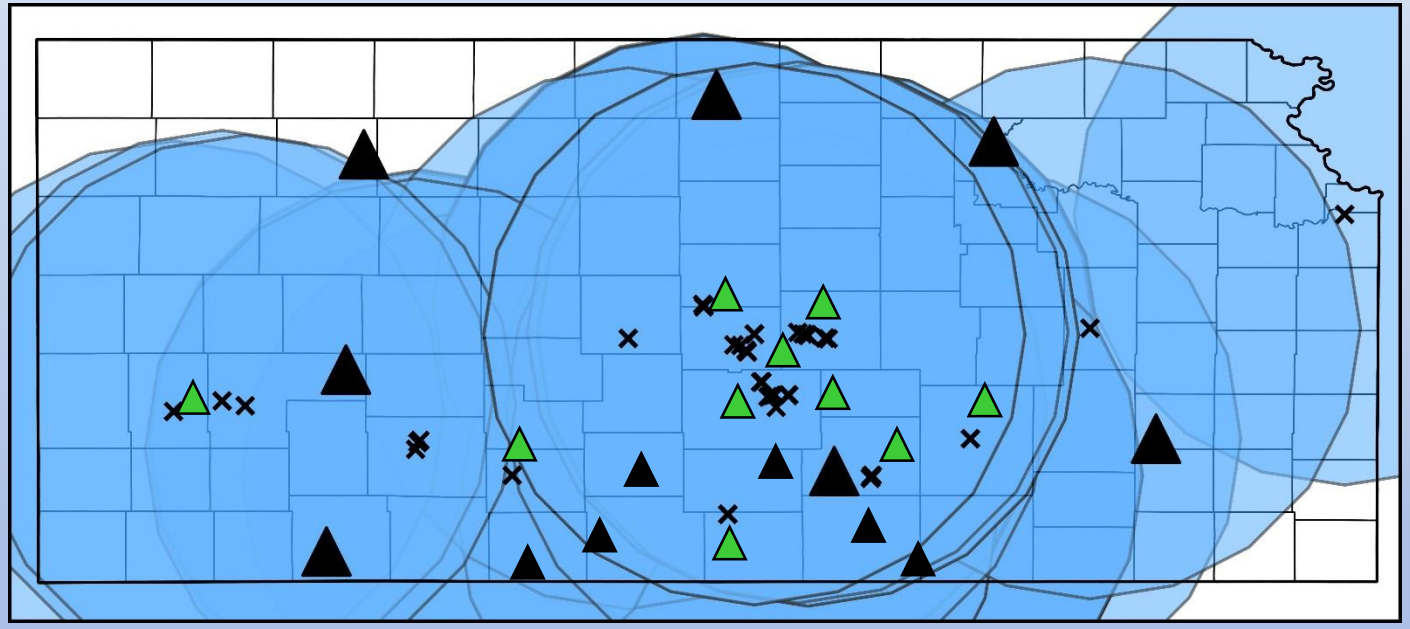
radius around all class I wells, must have 3 stations to locate



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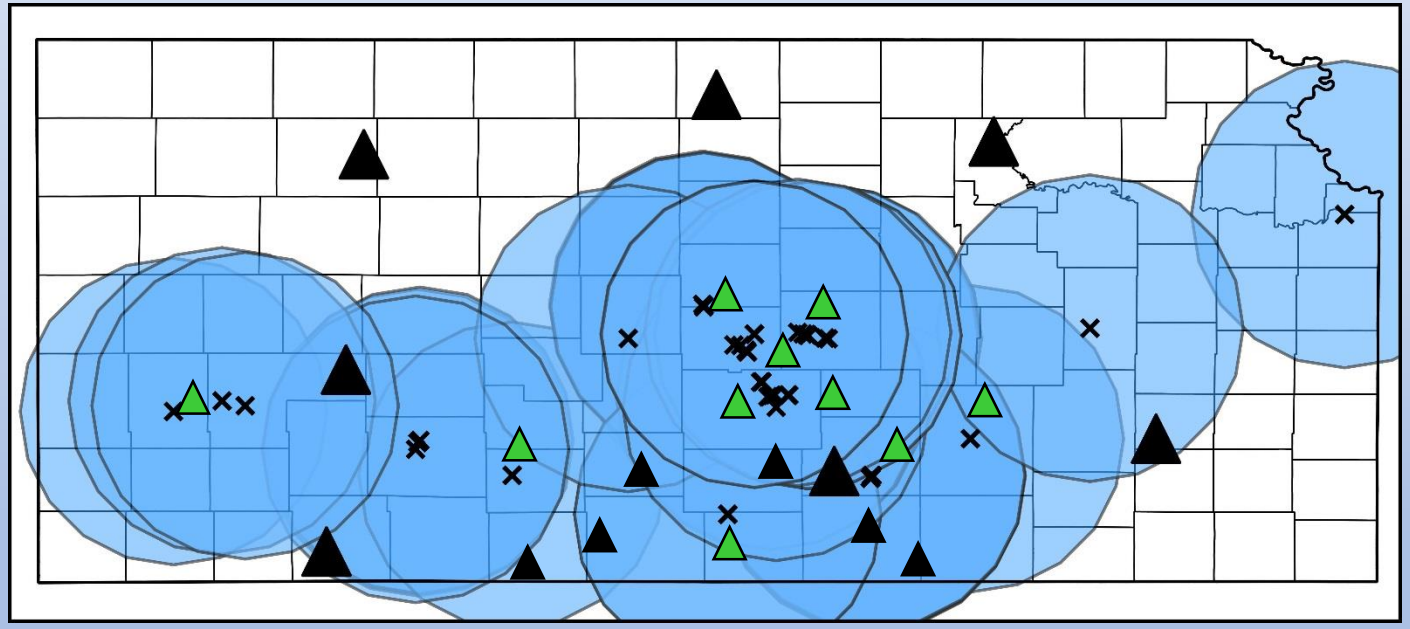

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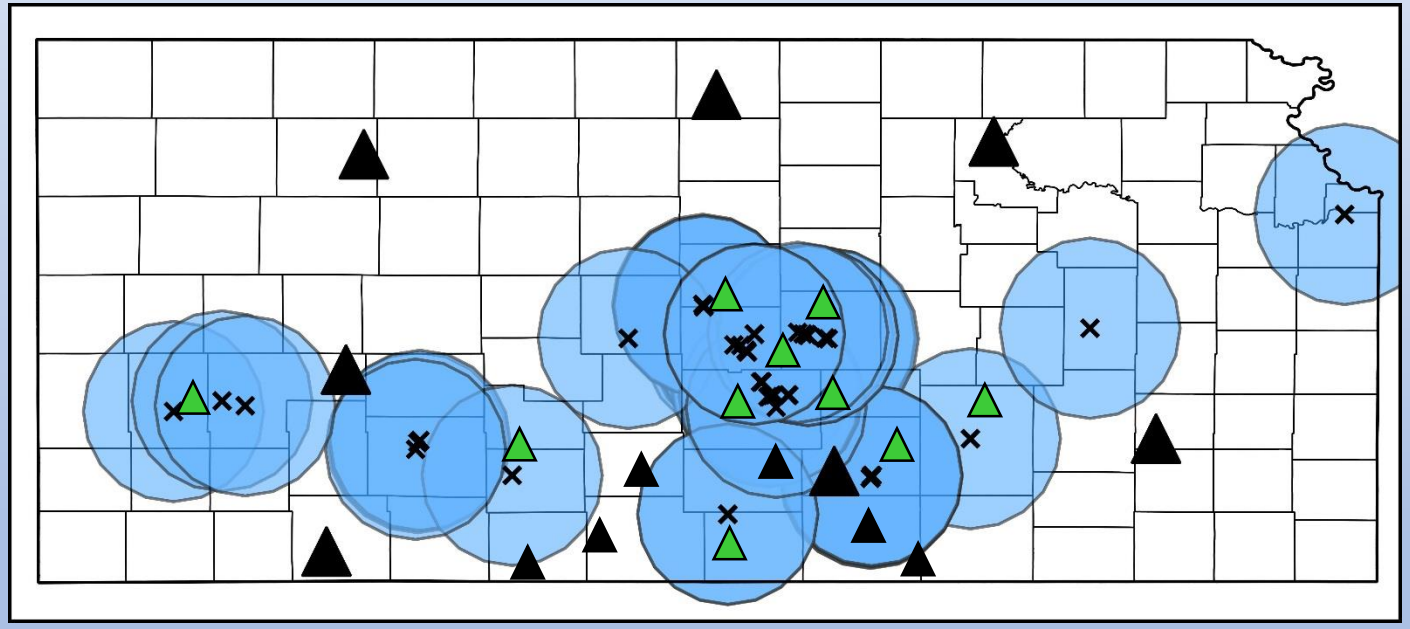
M 1-1.5 (50 km)

radius around all class I wells, must have 3 stations to locate



X class I well

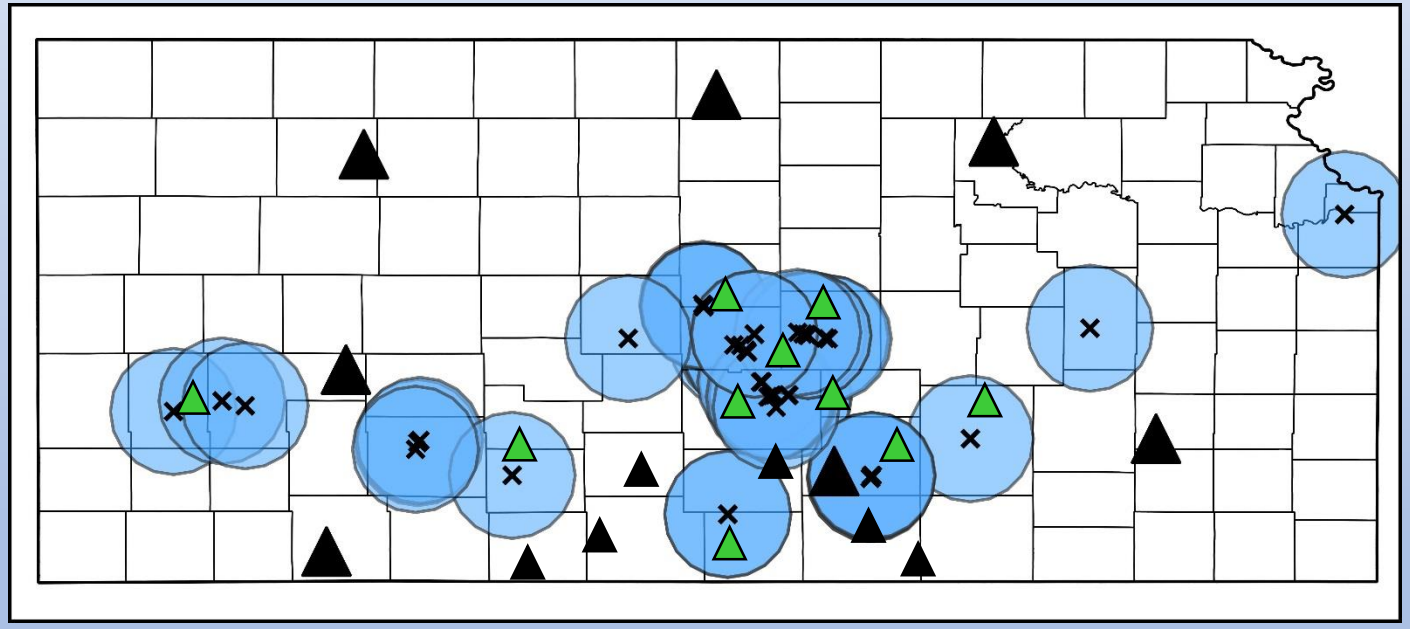
▲ KGS seismic station

△ Consortium station

Minimum Member Design

M 0.5-1 (35 km)

radius around all class I wells, must have 3 stations to locate



X class I well

▲ KGS seismic station

△ Consortium station

Site Selection

Characteristics We Want

- Sun exposure
- Quiet
- Secluded/secure

Things to Avoid

- Trees
- Noise
  - highways
  - power lines
  - pump jacks, etc.
  - trains
- Poor drainage

ideal station (Sun City)

Site Selection

Characteristics We Want

- Sun exposure
- Quiet
- Secluded/secure

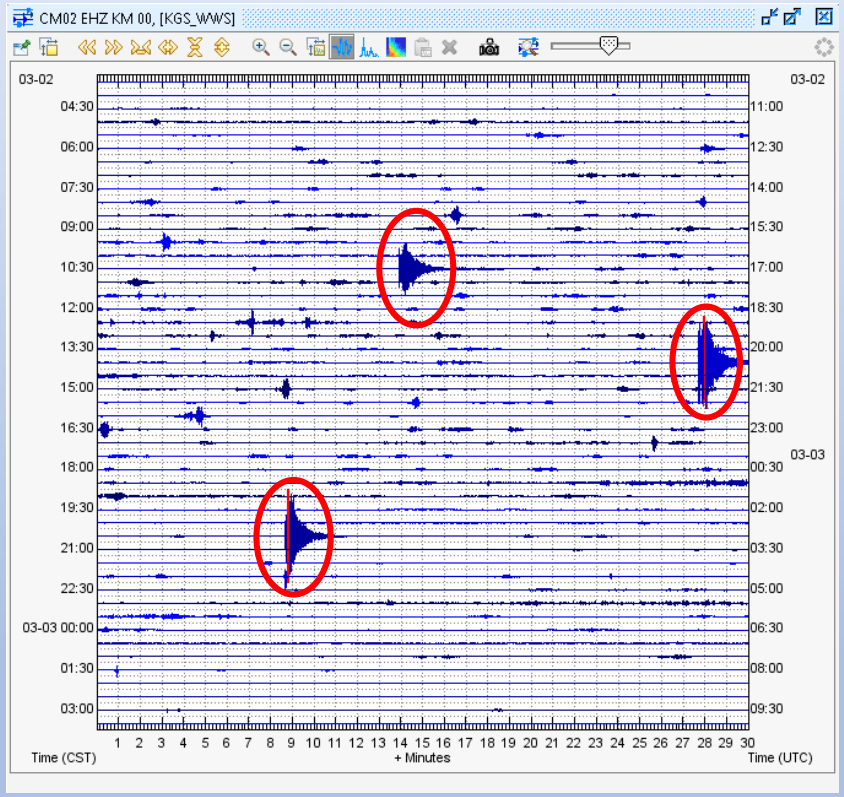
Things to Avoid

- **Trees**
- Noise
  - traffic
  - power lines
  - pump jacks, etc.
- Poor drainage

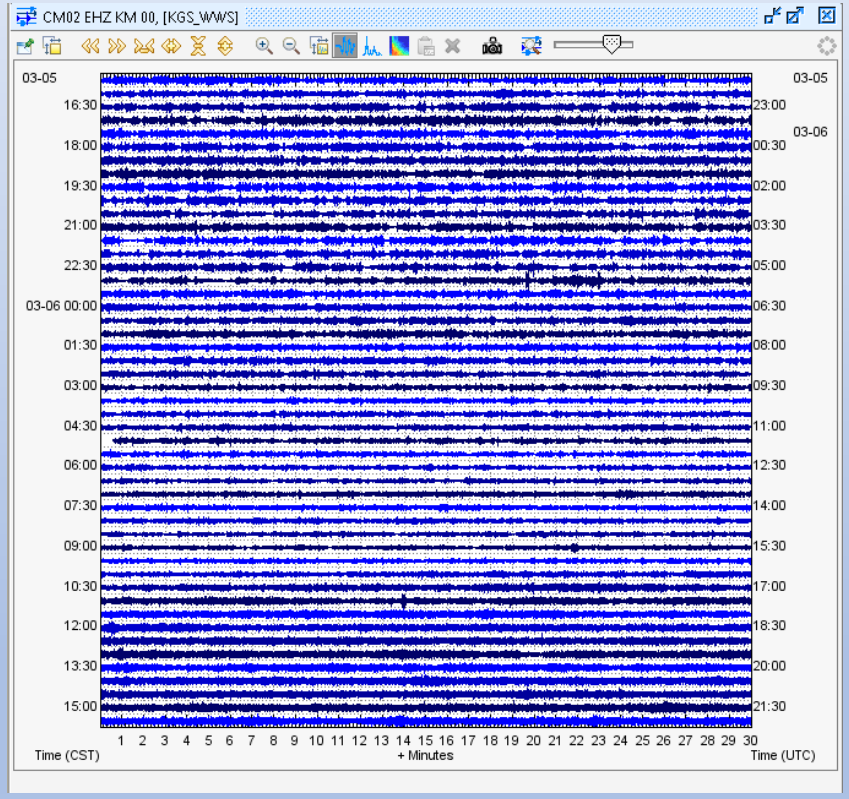
close trees

Example Wind Noise

quiet day



extreme wind



25-45 mph

Site Selection

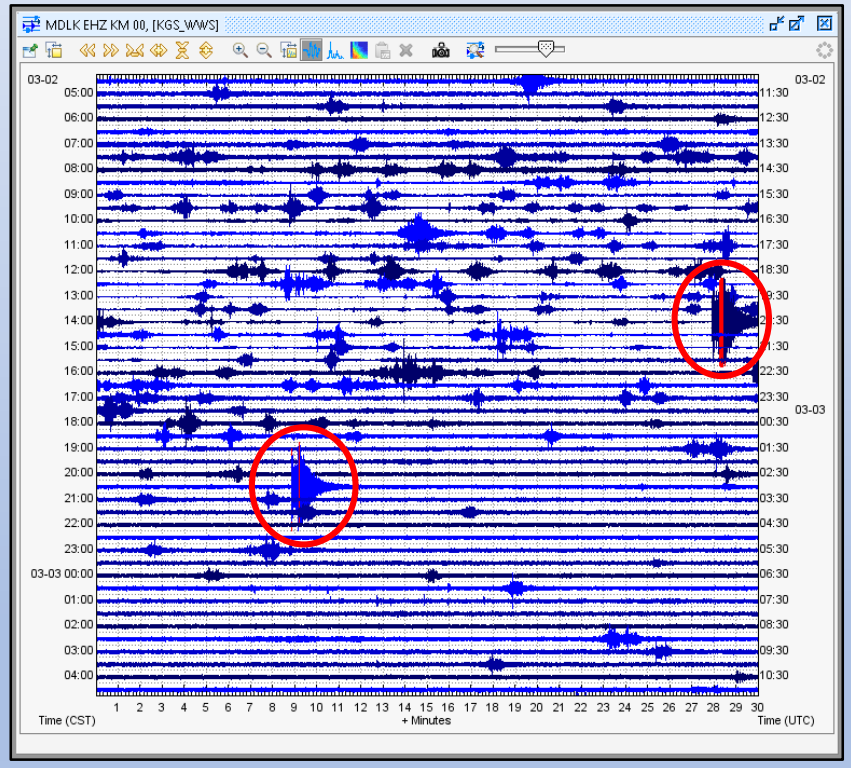
Characteristics We Want

- Sun exposure
- Quiet
- Secluded/secure

Things to Avoid

- Trees
- **Noise**
  - **traffic**
  - power lines
  - pump jacks, etc.
- Poor drainage

highway traffic



Site Selection

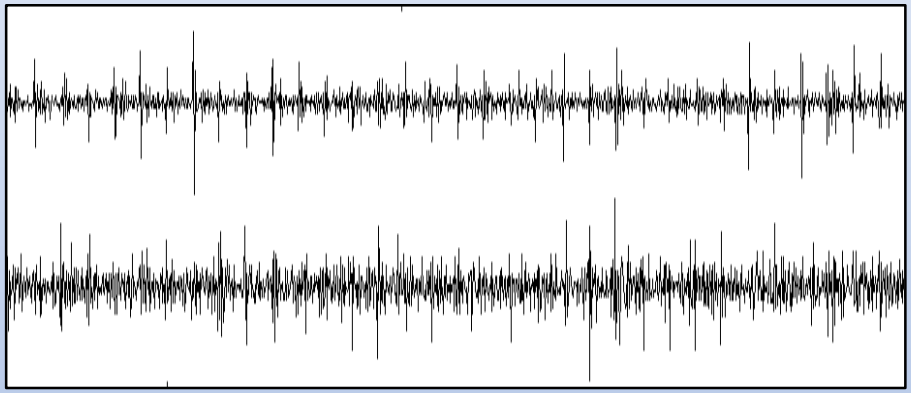
Characteristics We Want

- Sun exposure
- Quiet
- Secluded/secure

Things to Avoid

- Trees
- **Noise**
  - traffic
  - **power lines**
  - **pump jacks, etc**.
- Poor drainage

electrical noise



Site Selection

Characteristics We Want

- Sun exposure
- Quiet
- Secluded/secure

Things to Avoid

- Trees
- Noise
  - traffic
  - power lines
  - pump jacks, etc.
- **Poor drainage**

flooded vault

Current Locations

Sun City – private pasture

Current Locations

Finney Lake – KDWPT

Current Locations

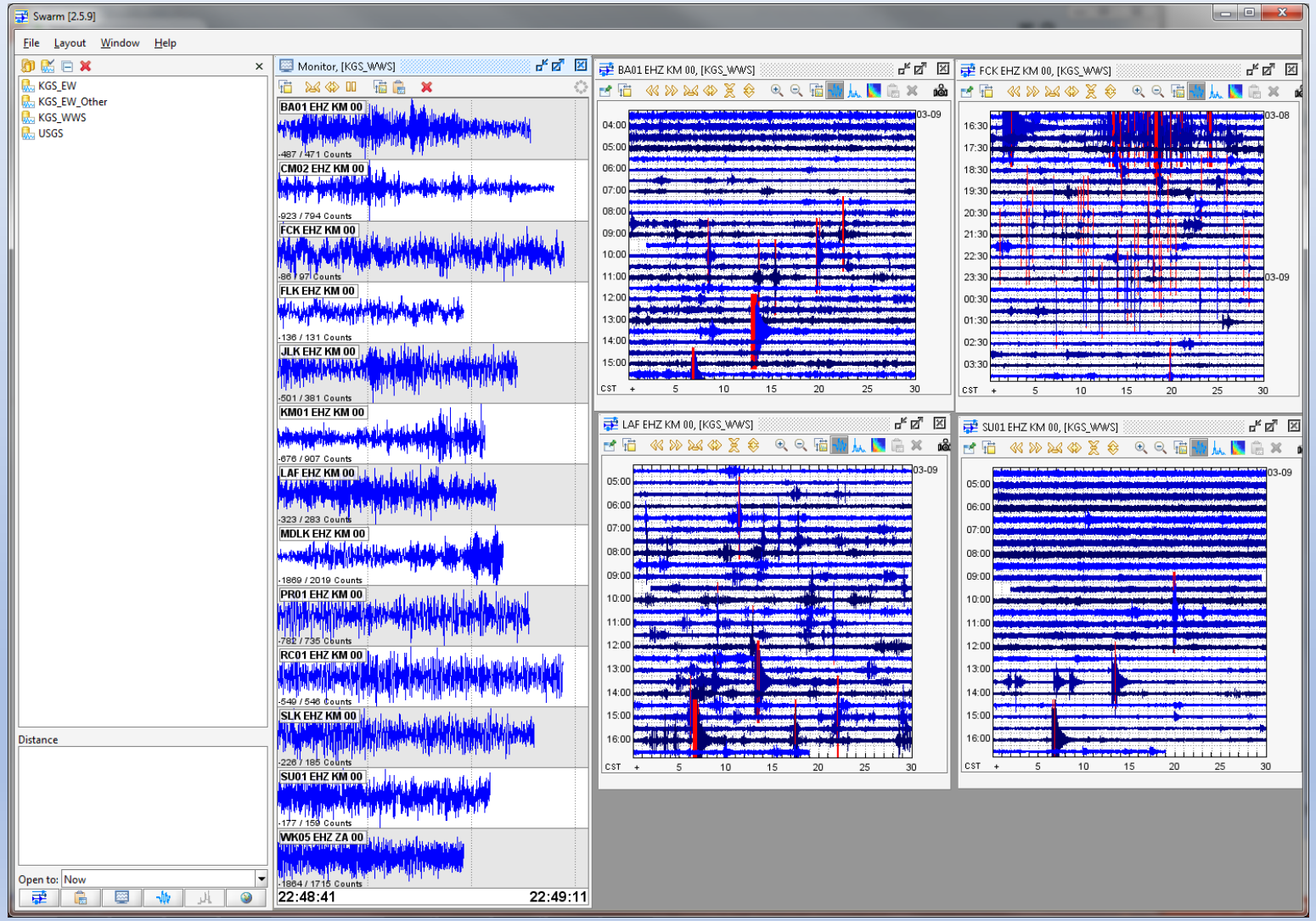
Fishery (Pratt) – KDWPT

Current Locations

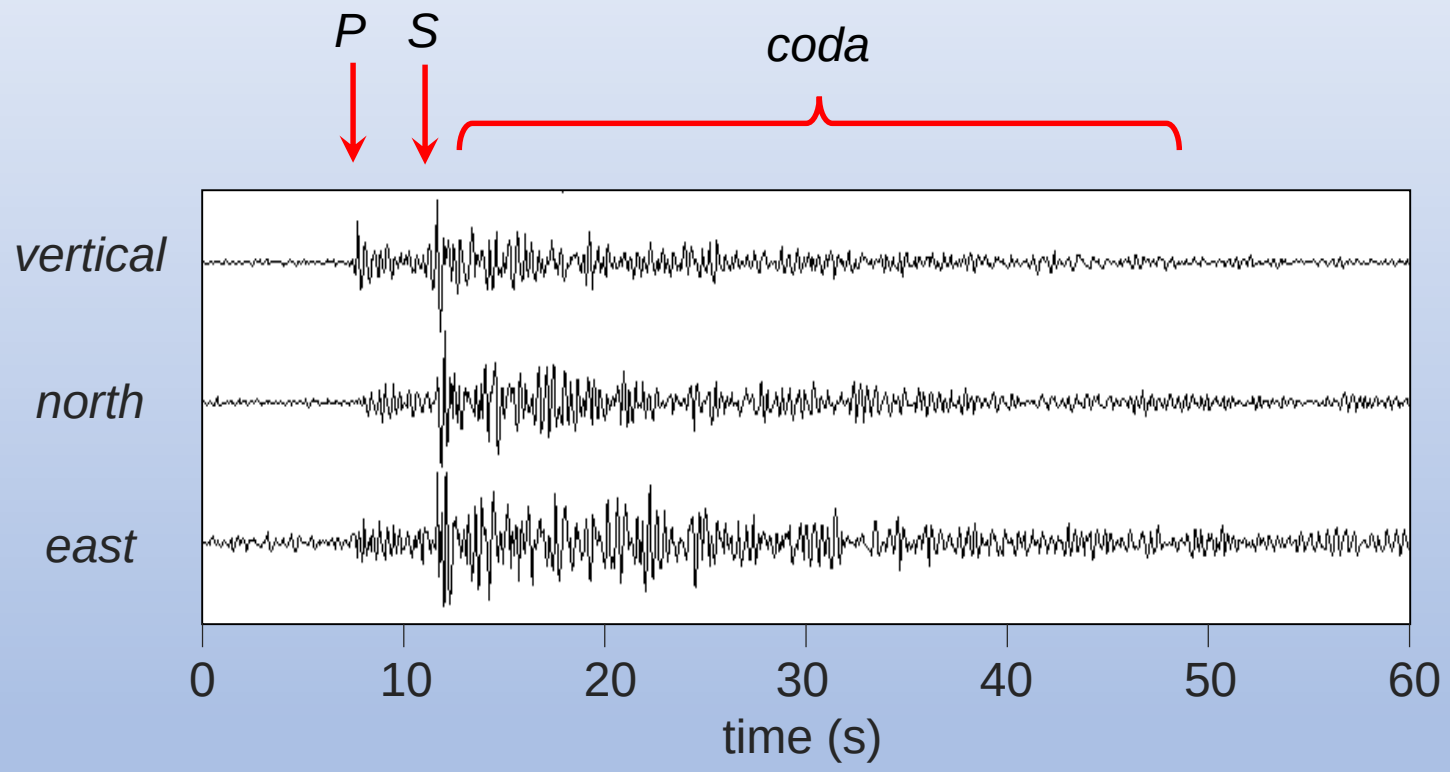
Sheridan Lake – KDWPT

Seismic Data and Earthquake Wavetrain

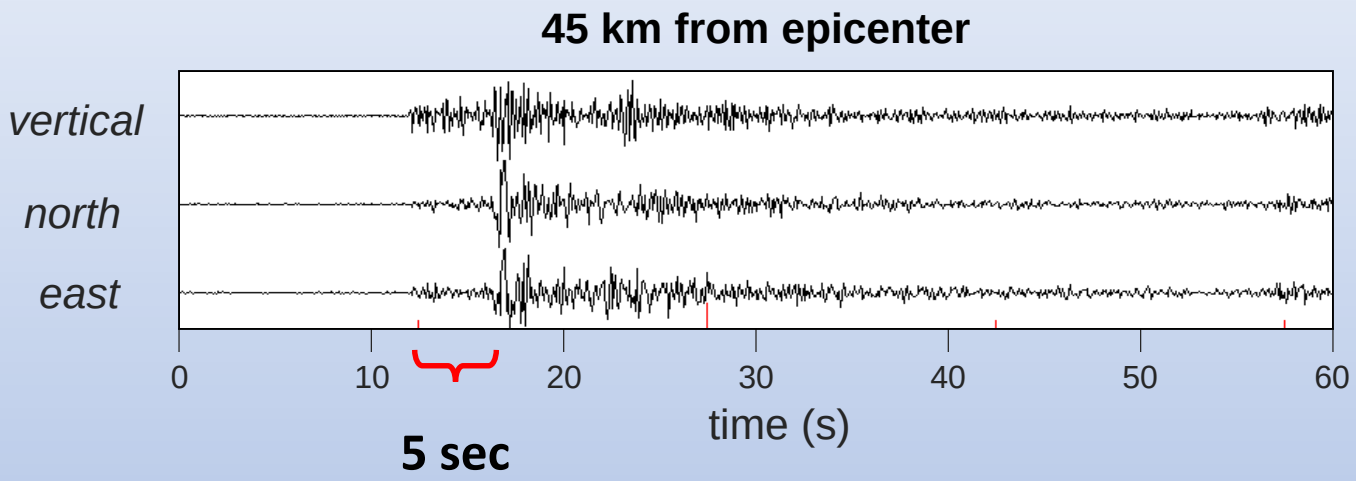
Live Feeds

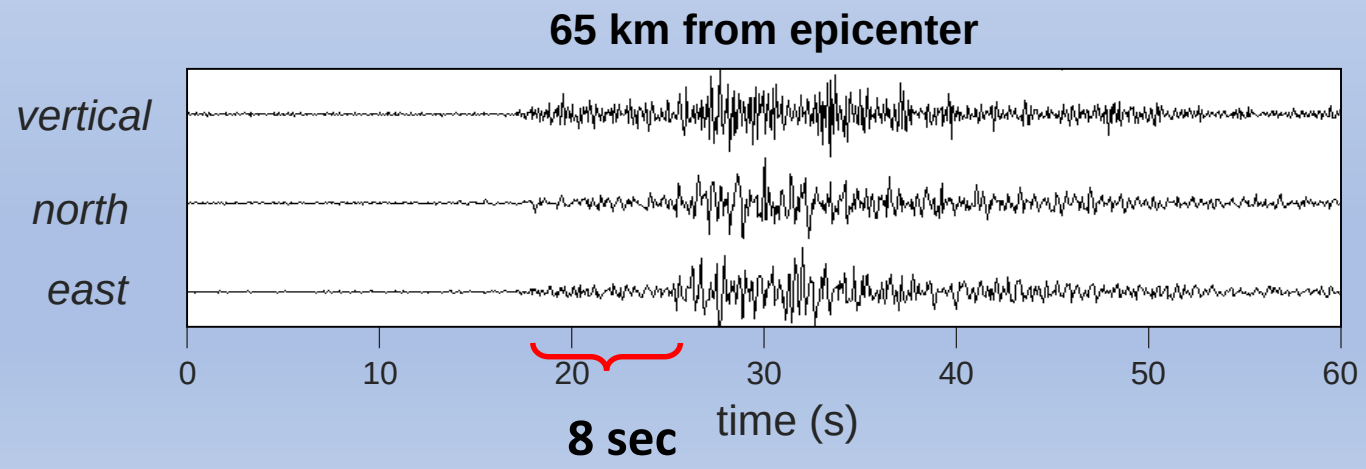

Swarm [2.5.9]
File Layout Window Help
KGS_EW
KGS_EW_Other
KGS_WWS
USGS
Distance
Open to: Now
Monitor, [KGS_WWS]
BA01 EHZ KM 00
CM02 EHZ KM 00
FCK EHZ KM 00
FLK EHZ KM 00
JLK EHZ KM 00
KM01 EHZ KM 00
LAF EHZ KM 00
MDLK EHZ KM 00
PR01 EHZ KM 00
RC01 EHZ KM 00
SLK EHZ KM 00
SU01 EHZ KM 00
WK05 EHZ ZA 00
22:48:41
22:49:11
BA01 EHZ KM 00, [KGS_WWS]
FCK EHZ KM 00, [KGS_WWS]
LAF EHZ KM 00, [KGS_WWS]
SU01 EHZ KM 00, [KGS_WWS]

Earthquake Wavetrain



Earthquake Wavetrain

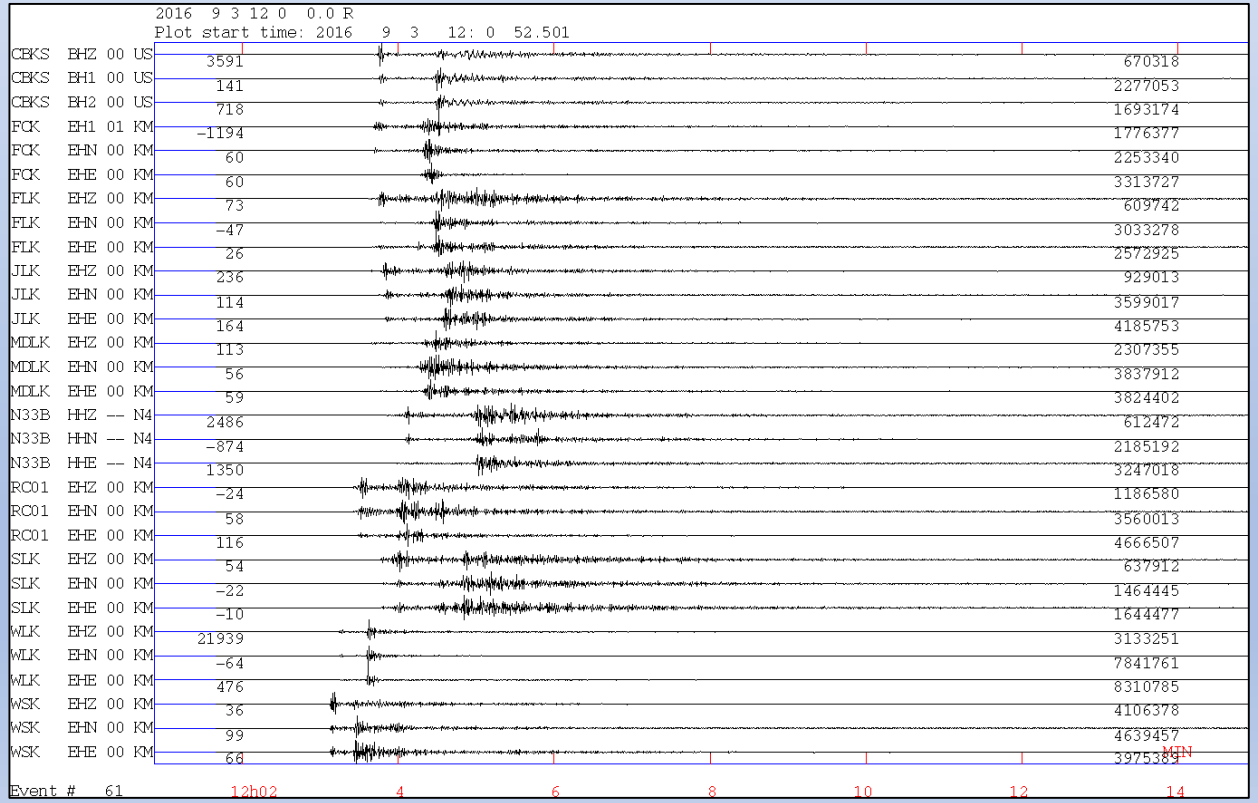




Oklahoma Earthquake

M 5.8

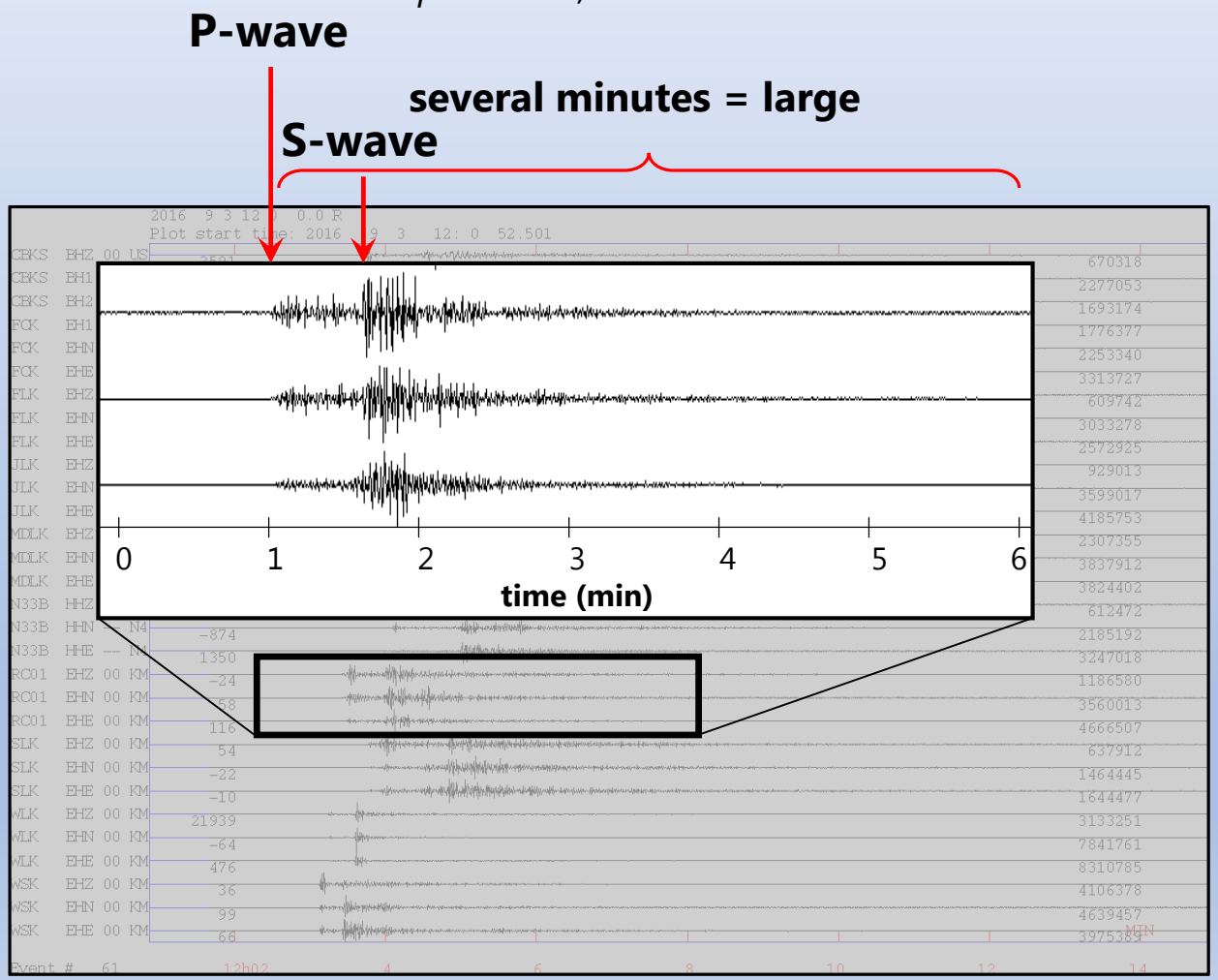
September 3, 2016 – Pawnee



Oklahoma Earthquake

M 5.8

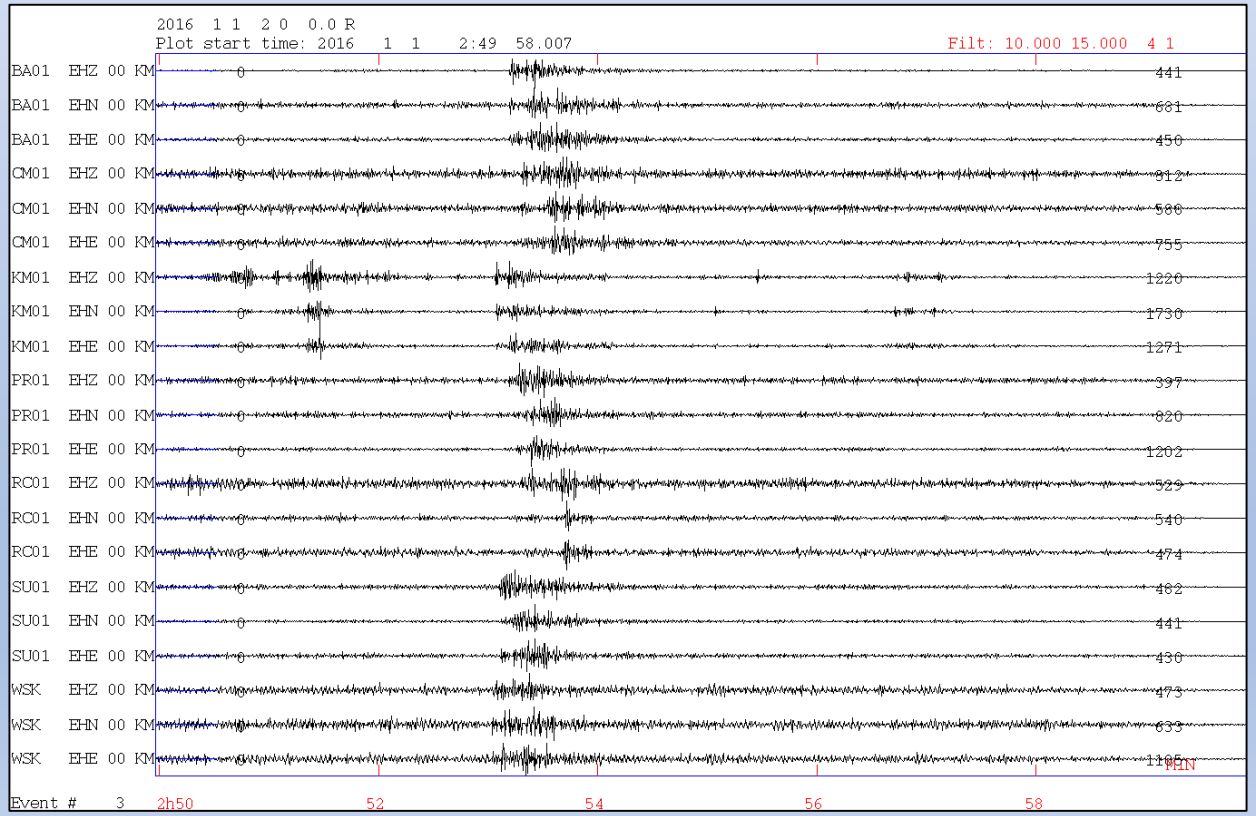
September 3, 2016 – Pawnee



Kansas Earthquake

M 2.0

January 1, 2016 – Harper Co.



Kansas Earthquake

M 2.0

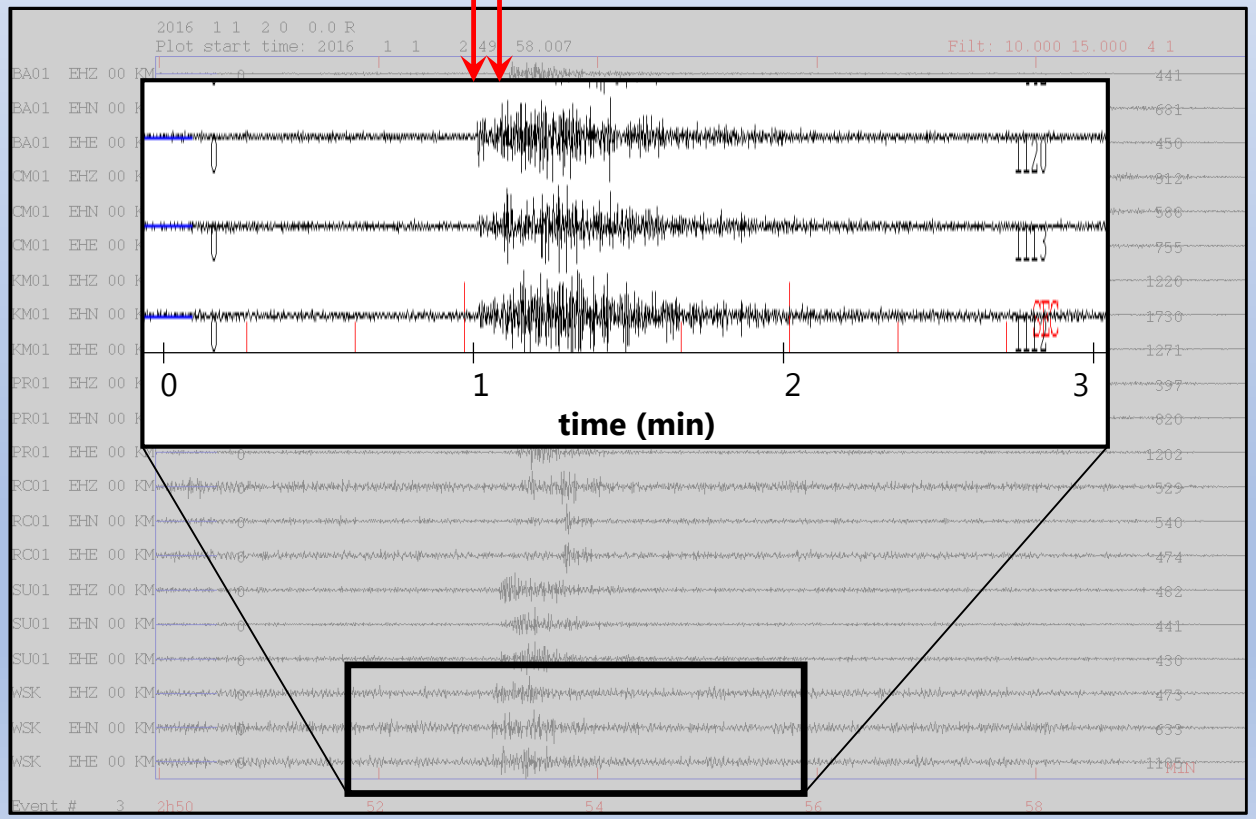
January 1, 2016 – Harper Co.

P-wave

S-wave

Δt = 5 s

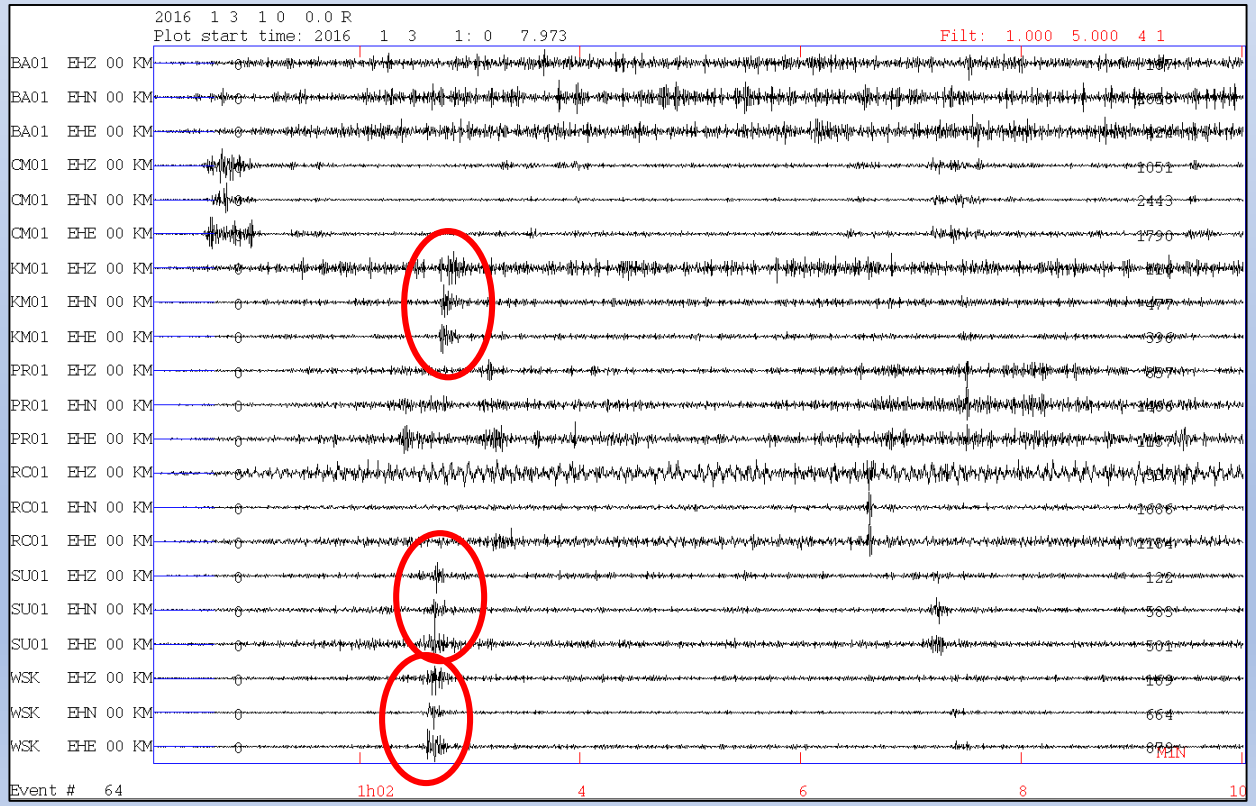
d > 40 km



Kansas Earthquake

M 1.5

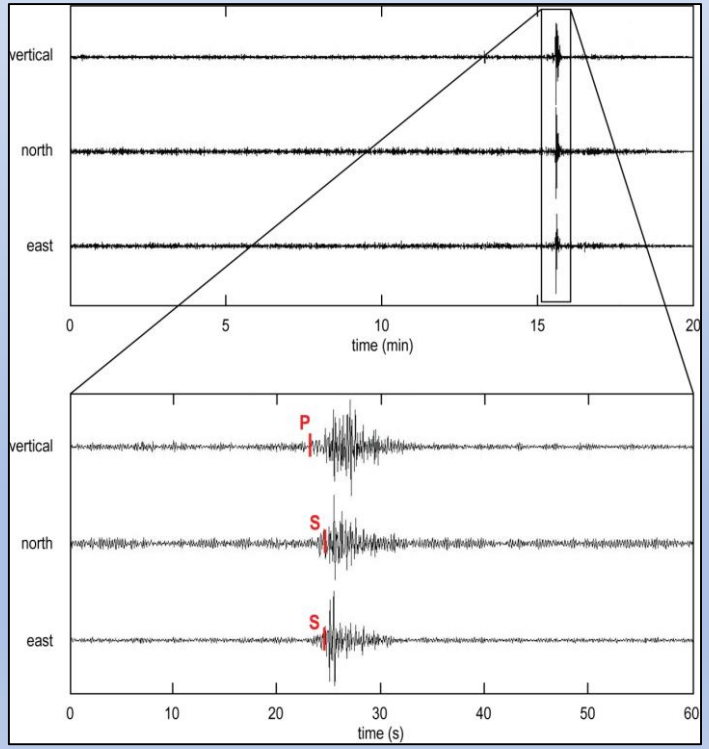
January 3, 2016 – Harper Co.



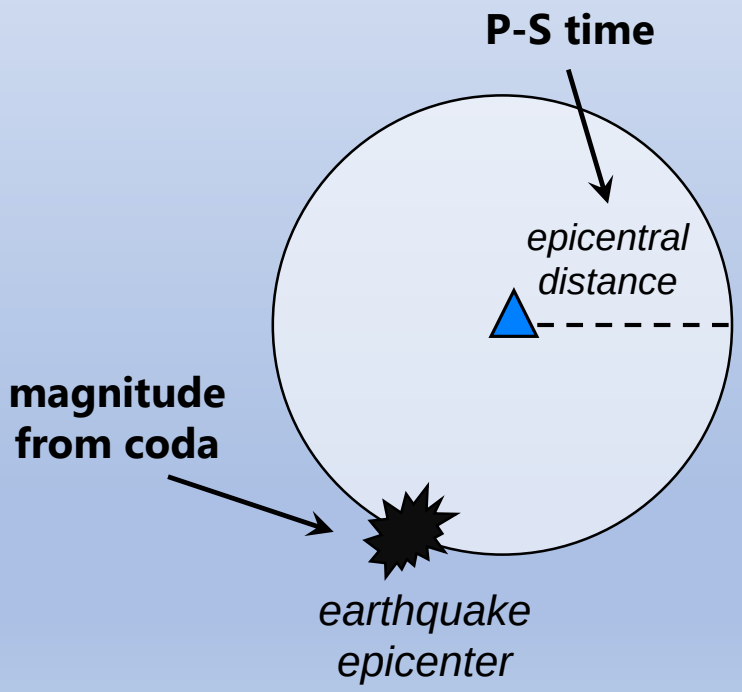
Locating Earthquakes

detected at 1 station

seismic data



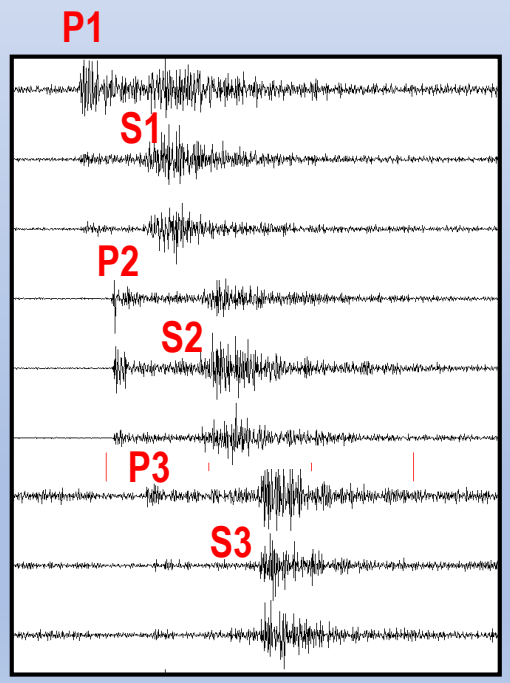
triangulate



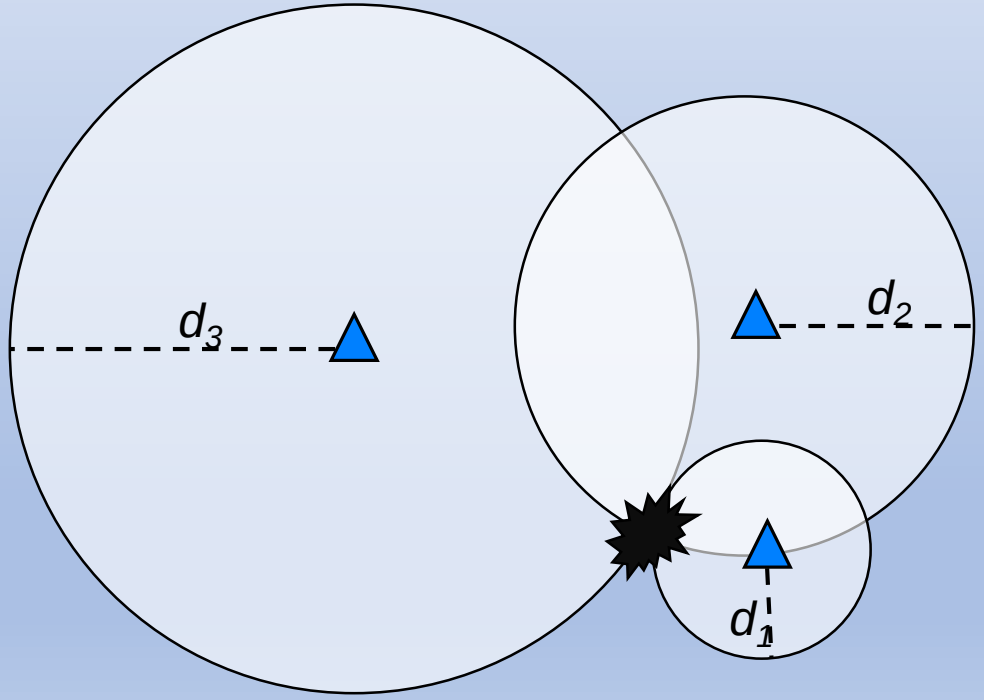
Locating Earthquakes

detected at ≥3 stations

seismic data

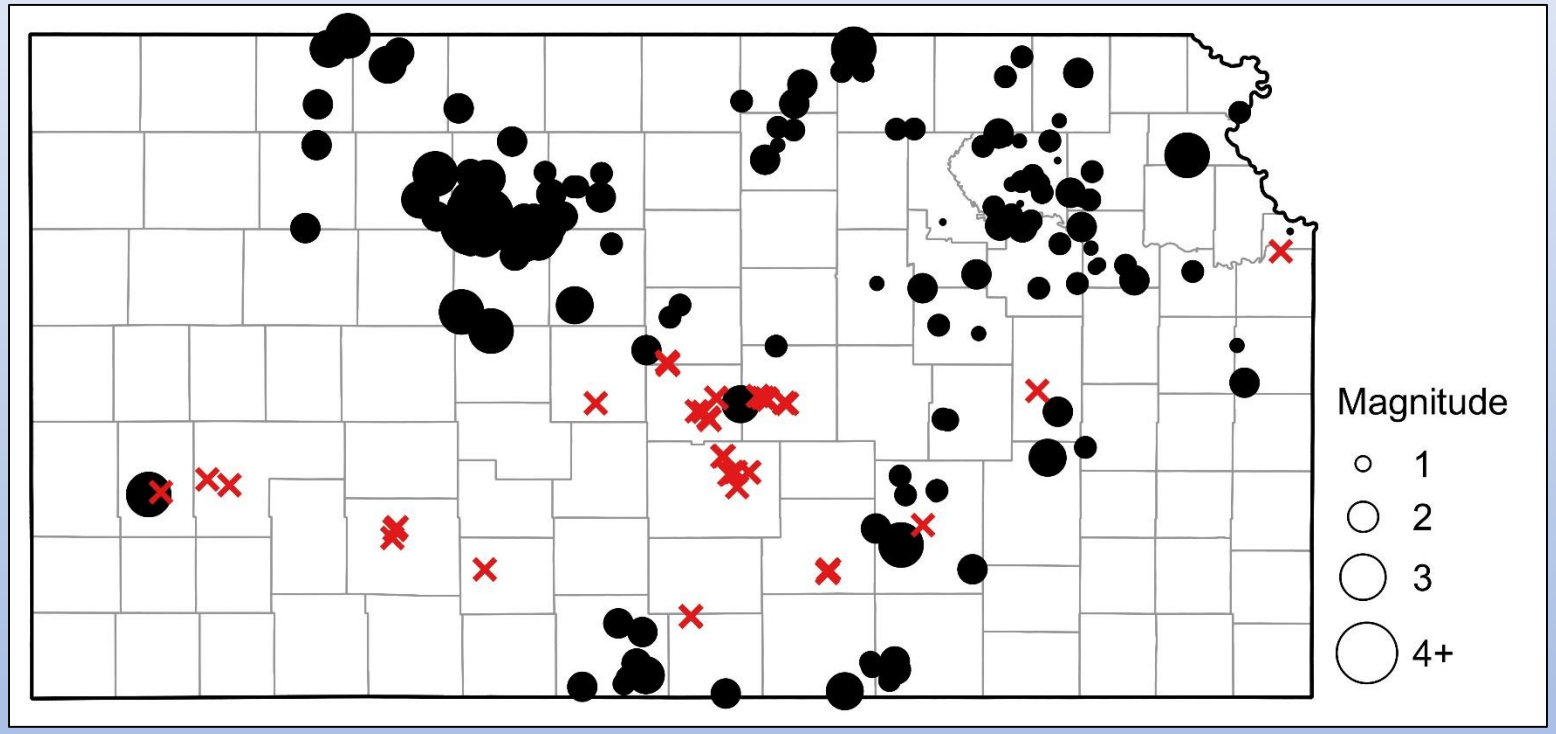


triangulate



Recent Earthquake Activity in Kansas

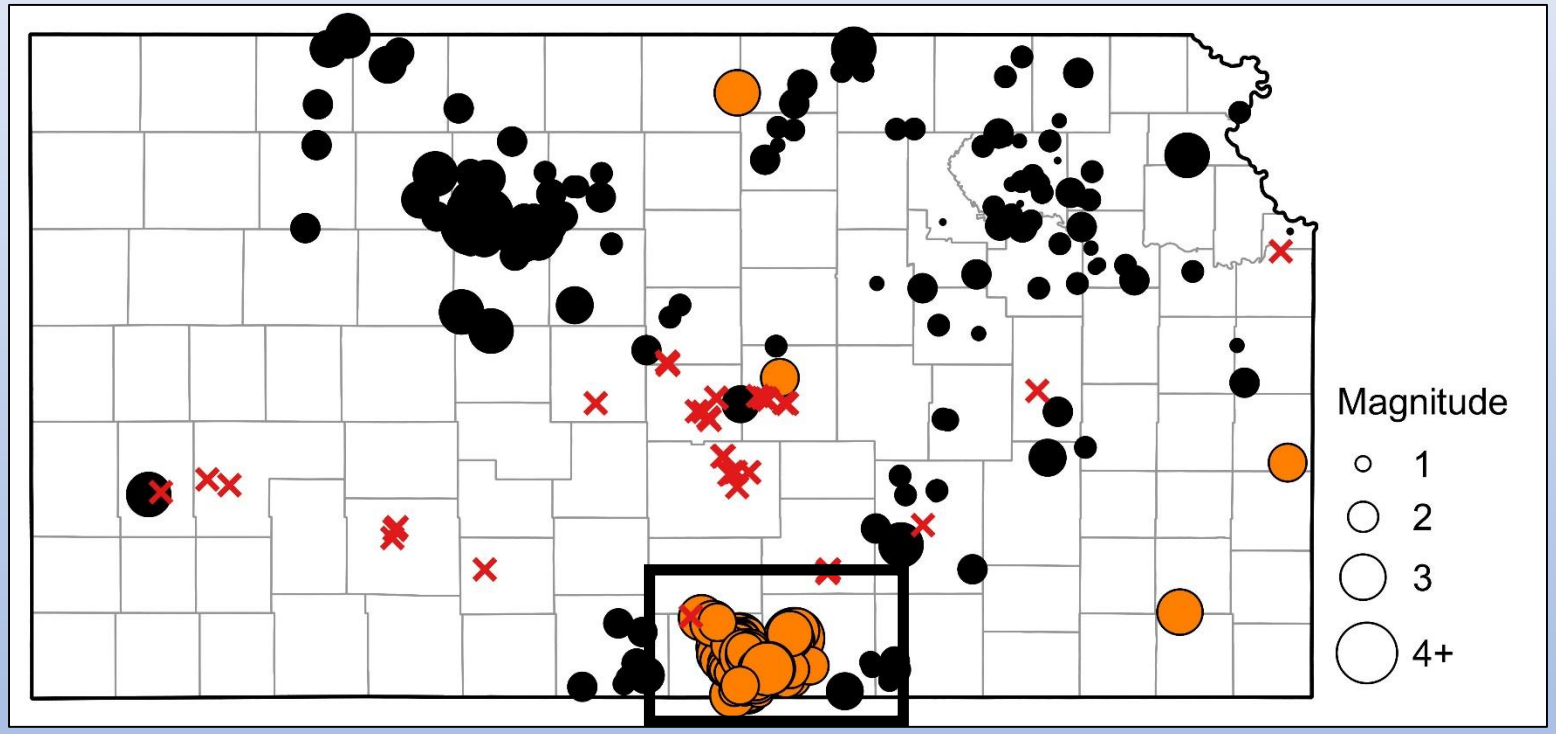
Historic Seismicity



● earthquake 1977-2012 (**<one** M≥3 per year)

X class I well

Potentially Induced Seismicity



earthquake 1977-2012 (**<one** M≥3 per year)

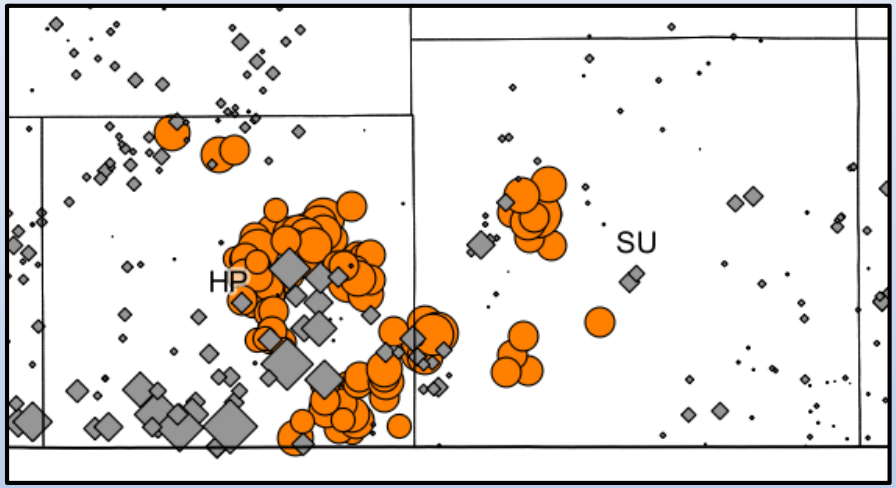
earthquake 2013-2014 (**50** per year)

X class I well

Potentially Induced Seismicity

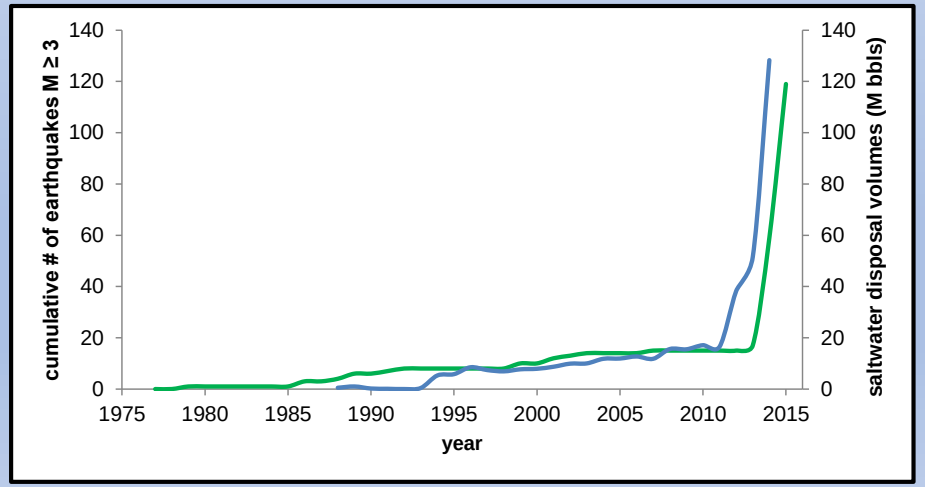
earthquake 2013-2014

class II SWD

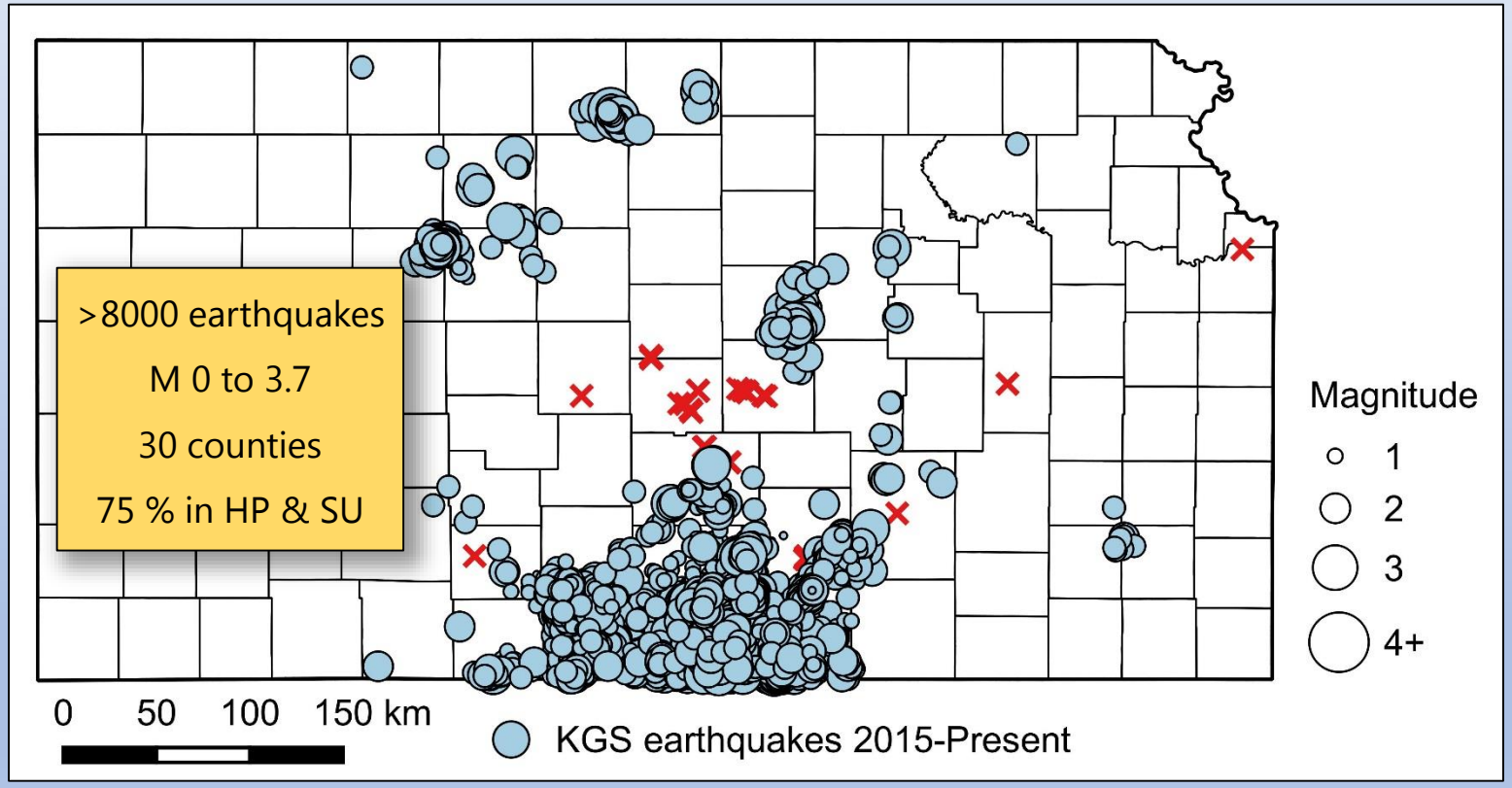


M3+ earthquake

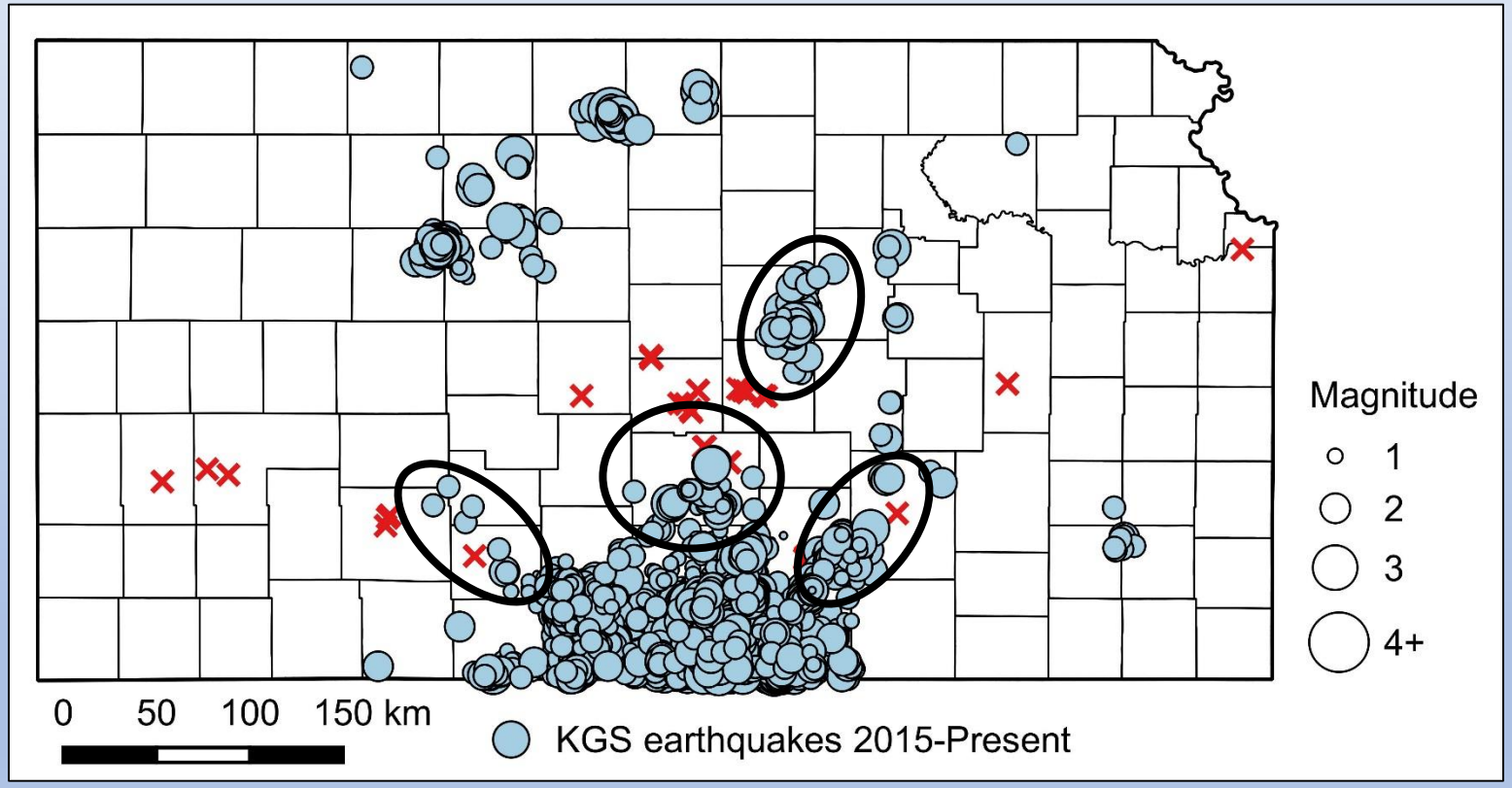
annual SWD volume



KGS Network: 2015-Present

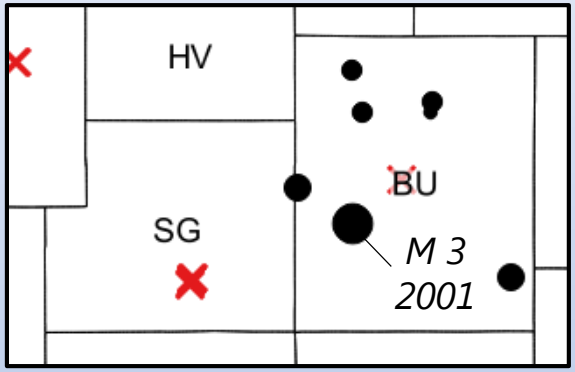


KGS Network: 2015-Present

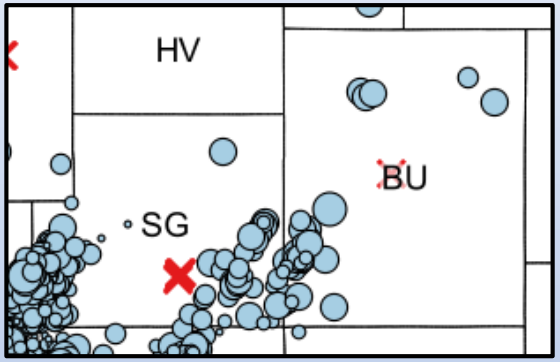


Recent Trends: Sedgwick/Butler

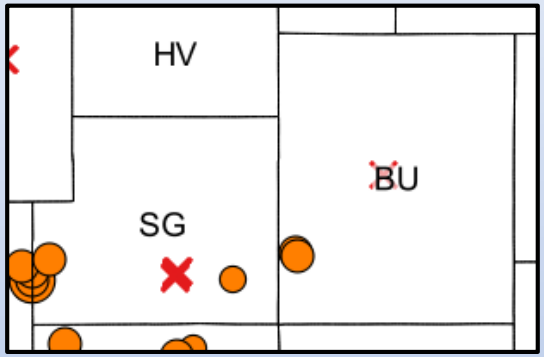
Historic (1977-2012)

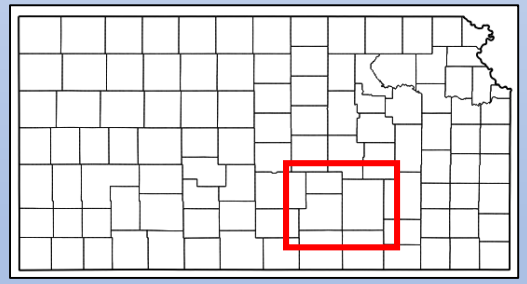


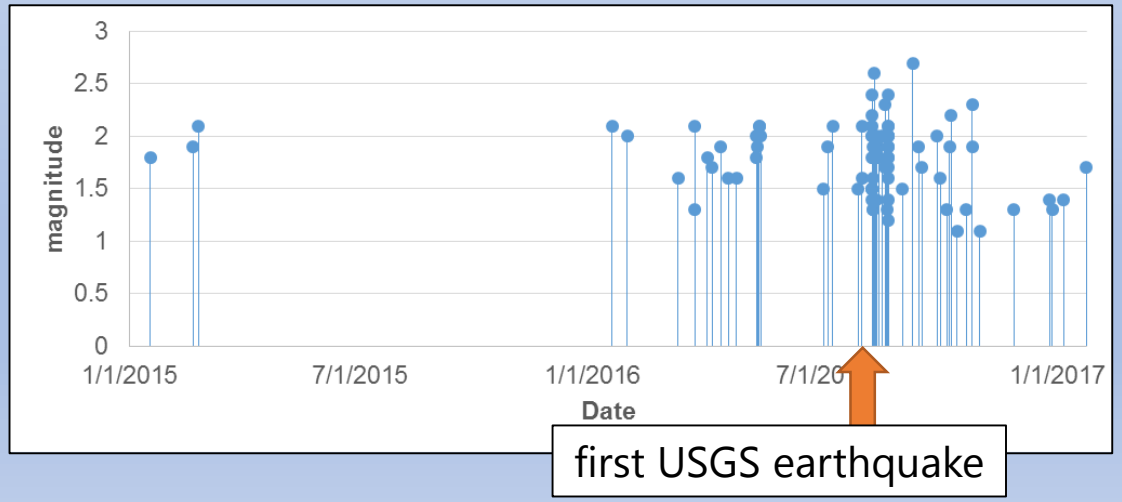
KGS (89) – 31 M≥2



USGS (3)

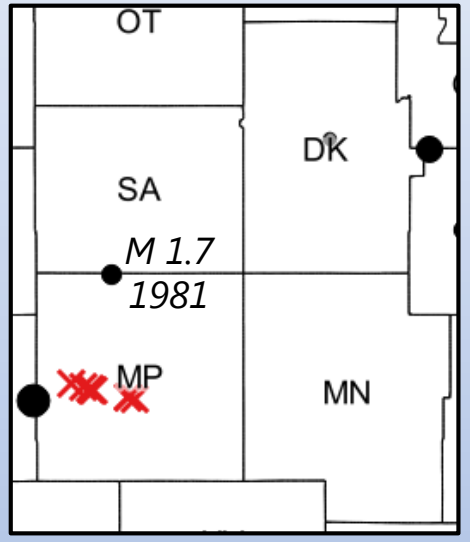




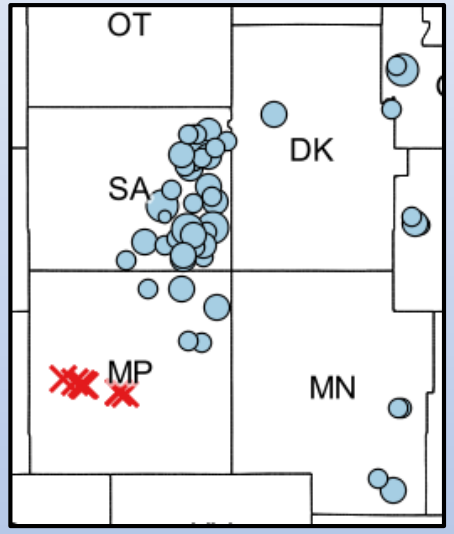


Recent Trends: Saline/McPherson

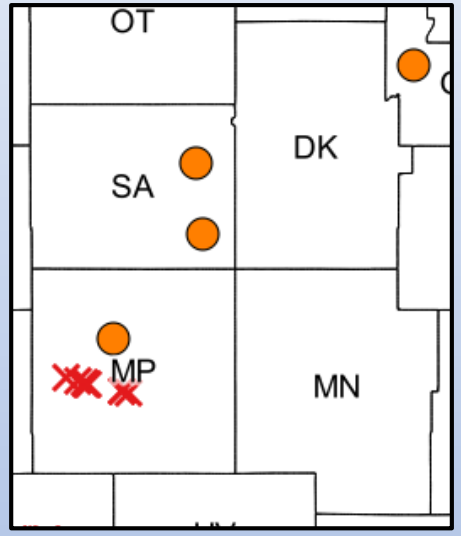
Historic (1977-2012)

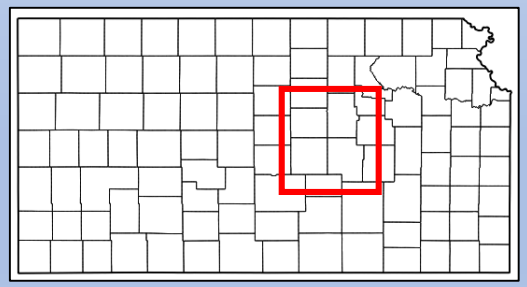


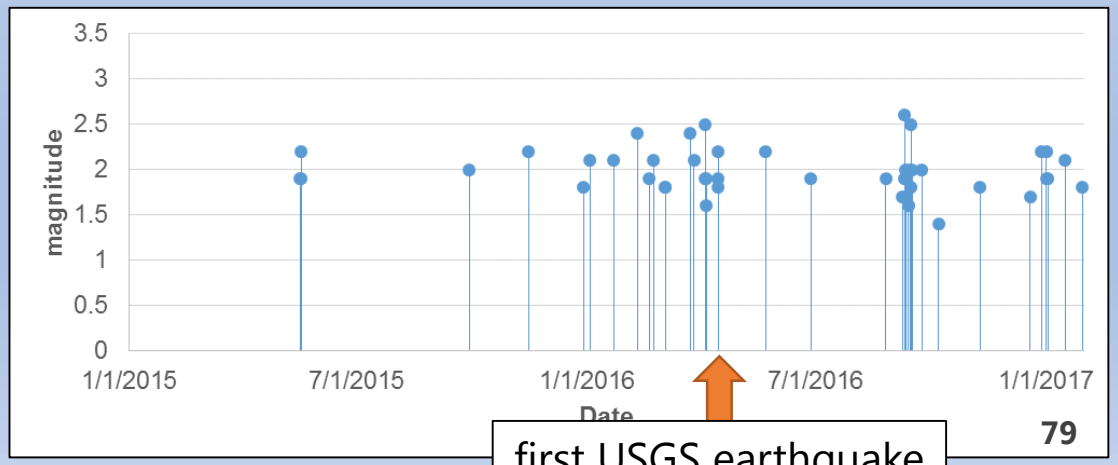
KGS (46) – 21 M≥2



USGS (3)



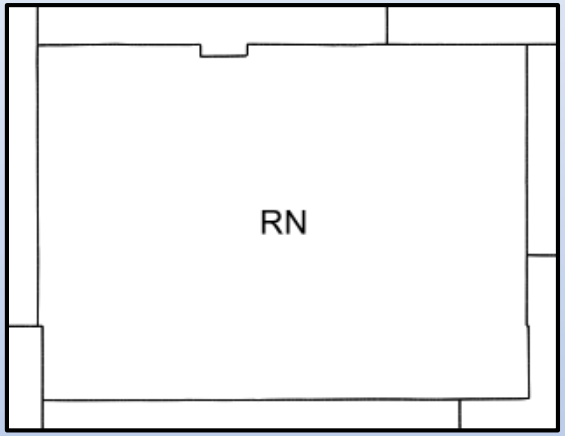




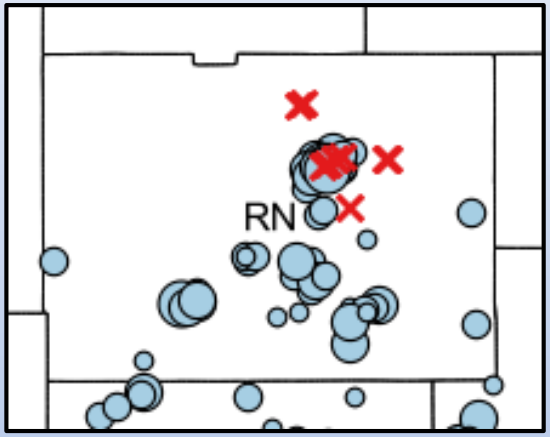
first USGS earthquake

Recent Trends: Reno

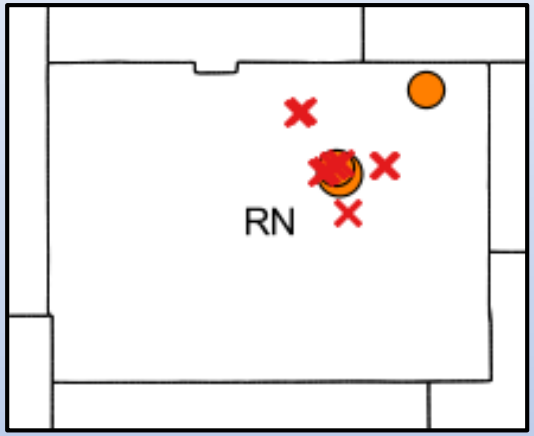
Historic (1977-2012)

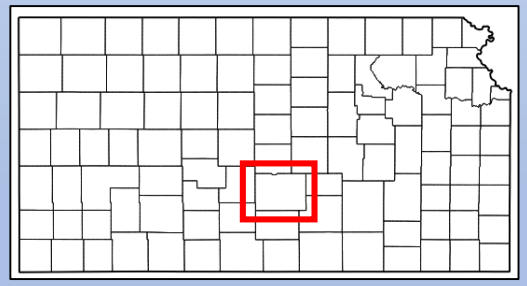


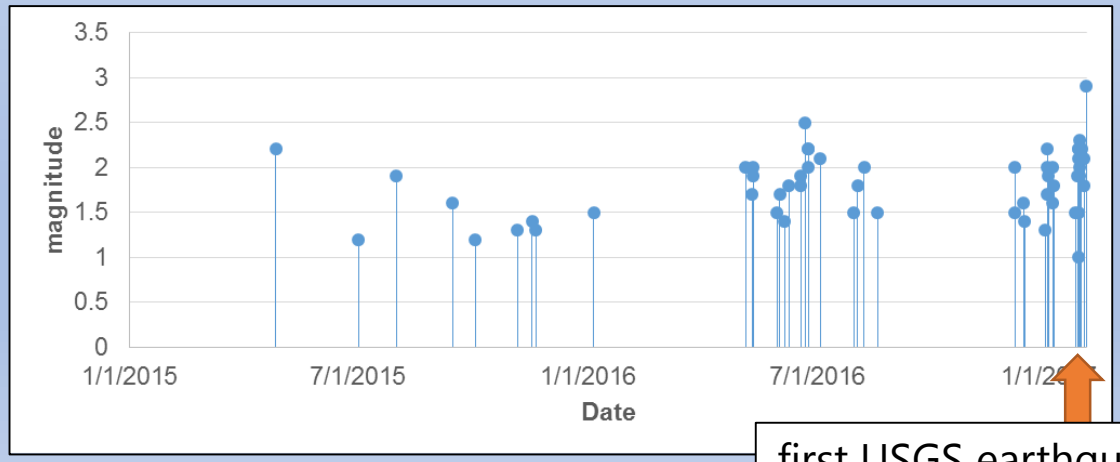
KGS (56) – 23 M≥2



USGS (3)



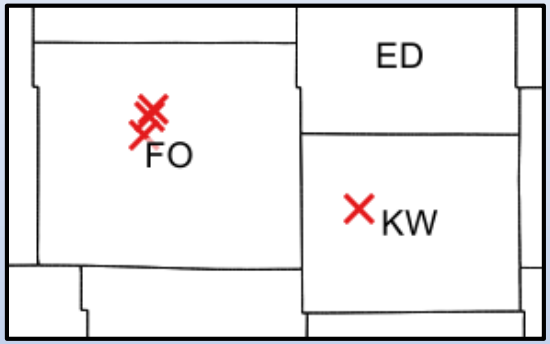




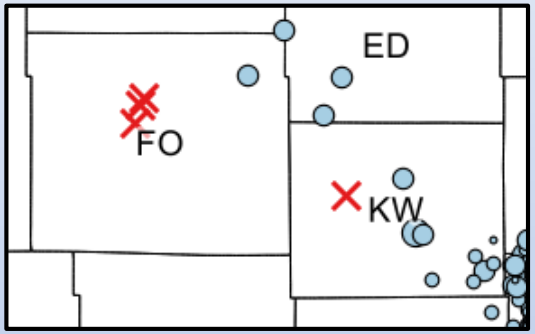
first USGS earthquake

Recent Trends: Kiowa/Ford

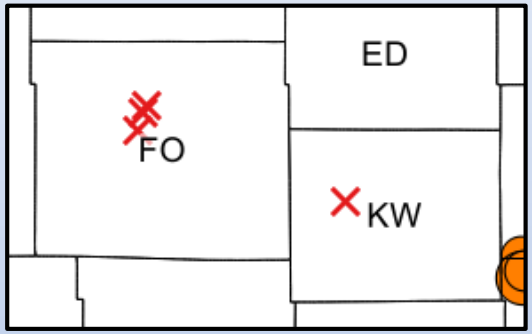
Historic (1977-2012)

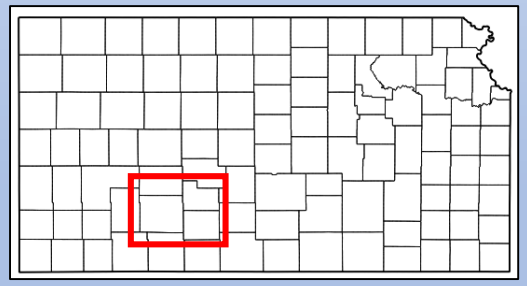


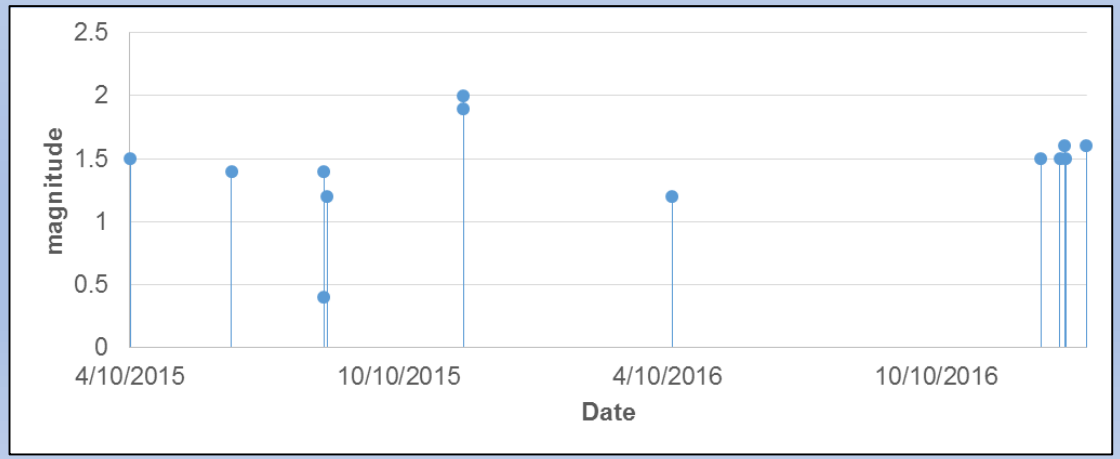
KGS (13) – 0 M≥2



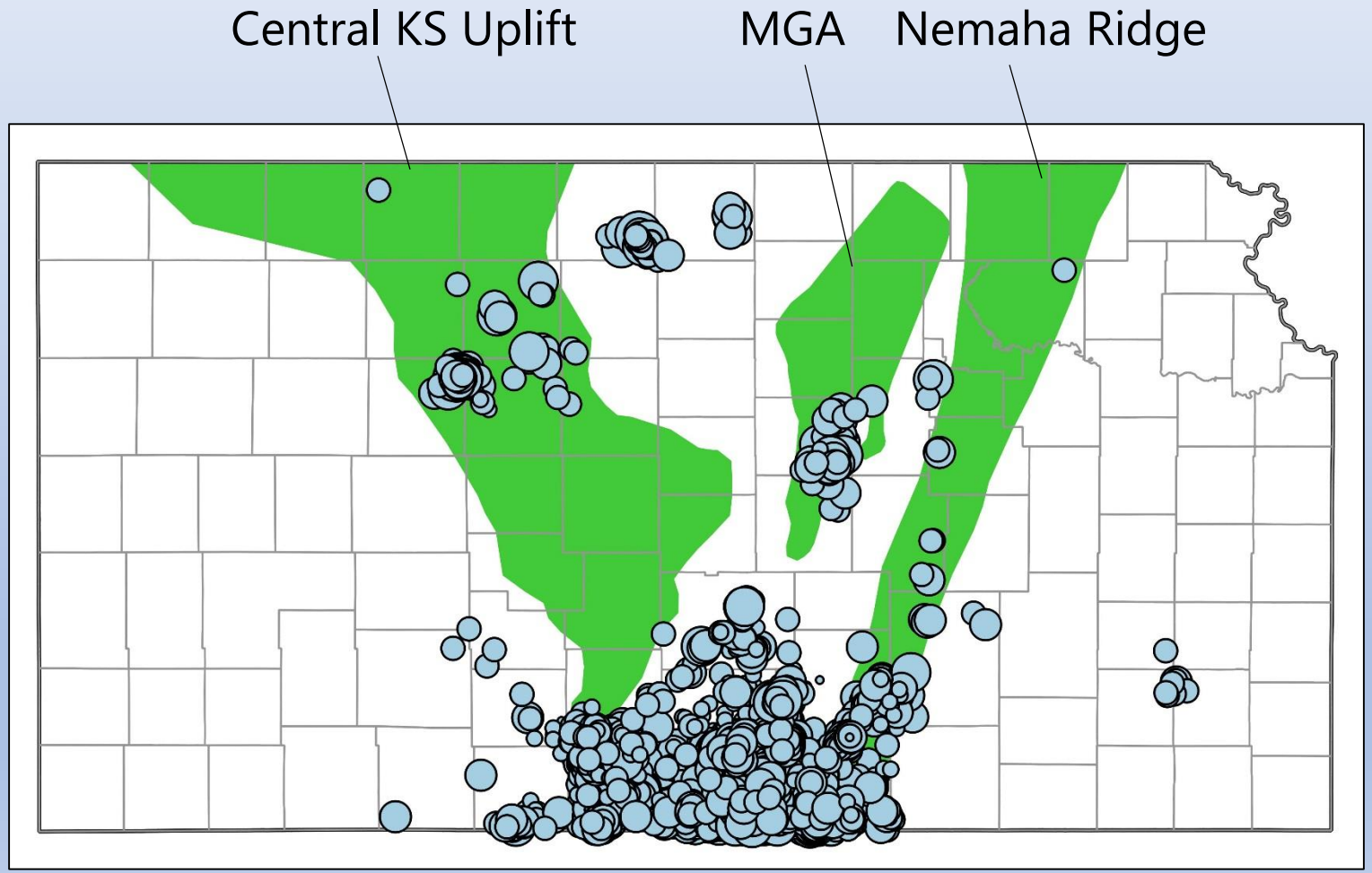
USGS (0)



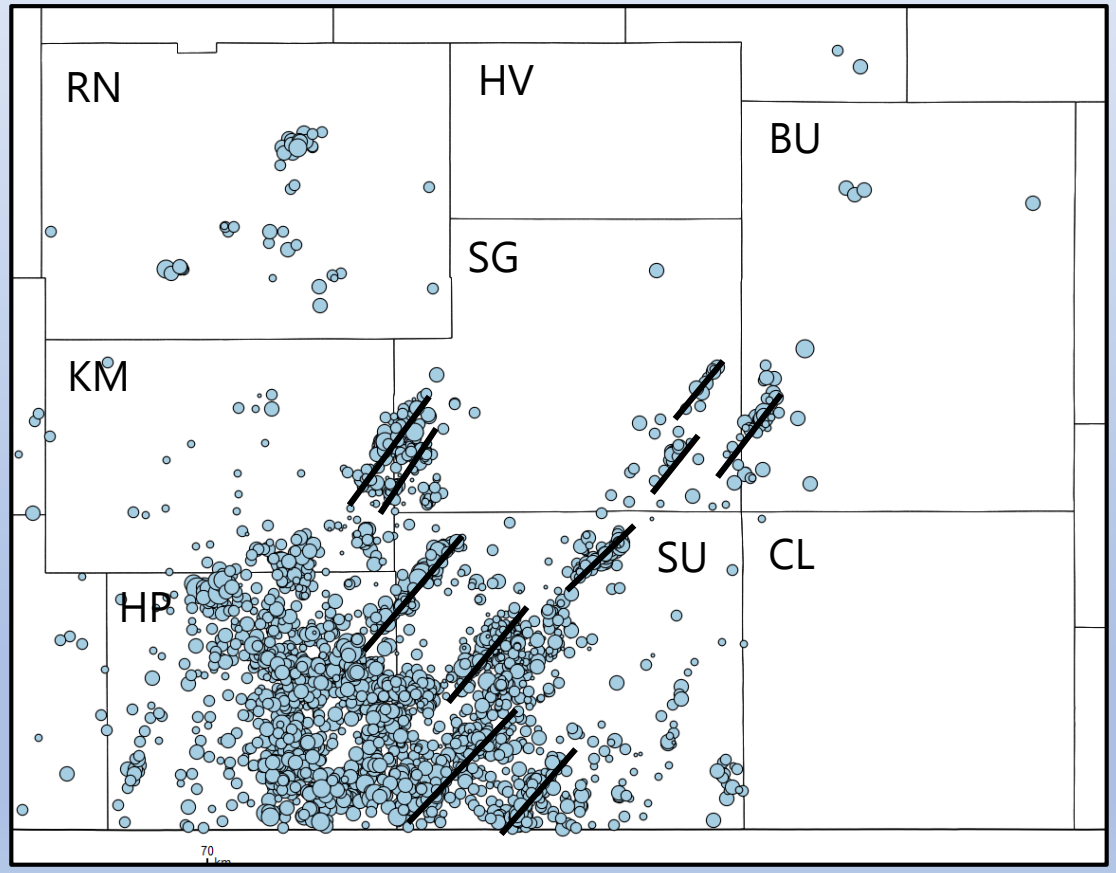




Earthquakes Along Structures



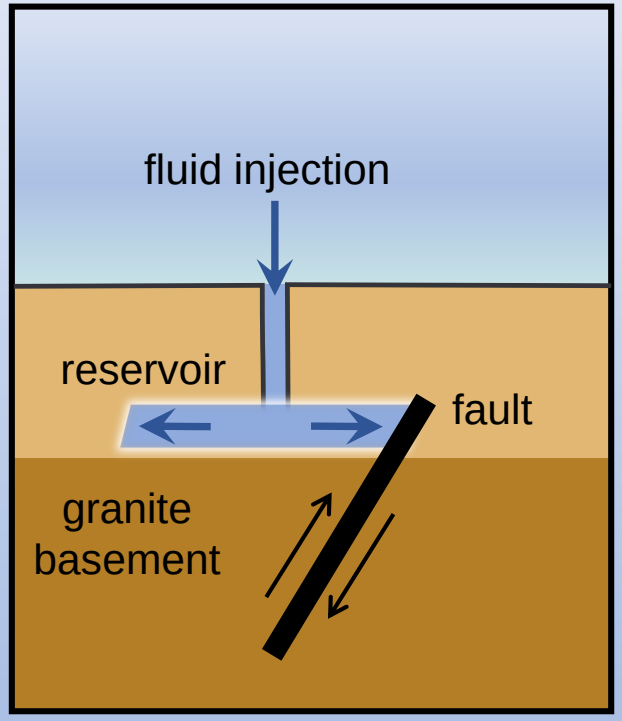
Earthquakes Along Structures



Trends in Fluid Level, Pressure & Injection

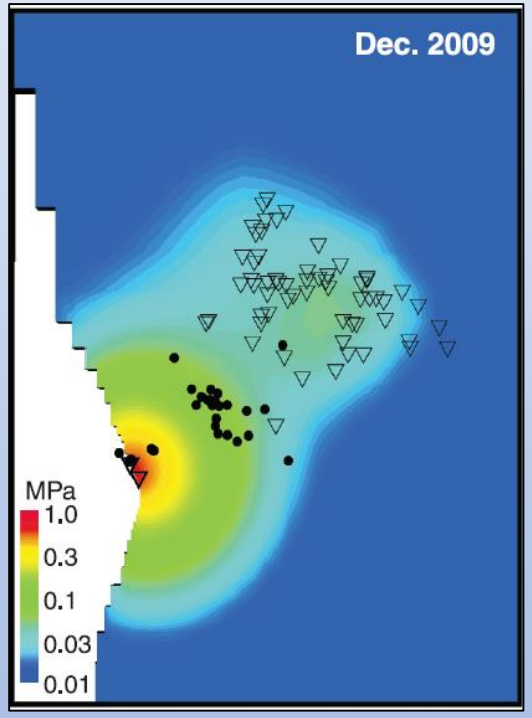
Primer on Induced Seismicity

profile view



after Ellsworth (2013)

map view

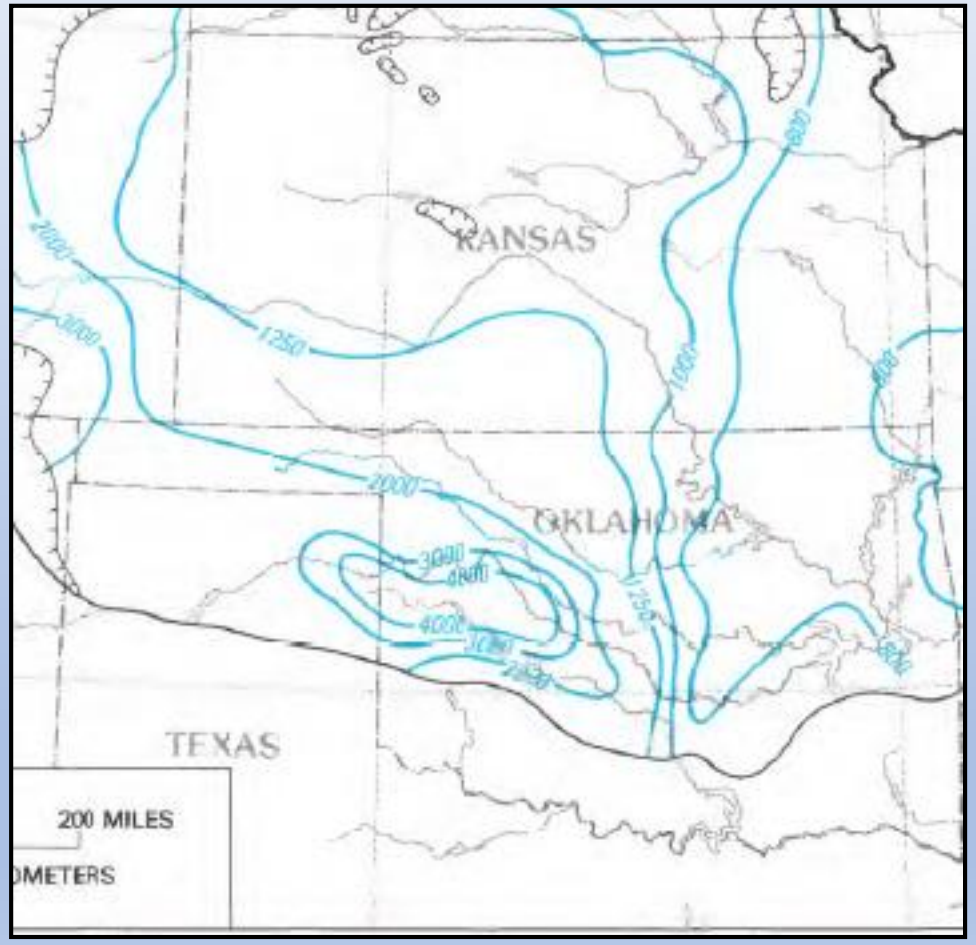


from Keranen et al. (2014)

fractured basement rocks, critically stressed faults

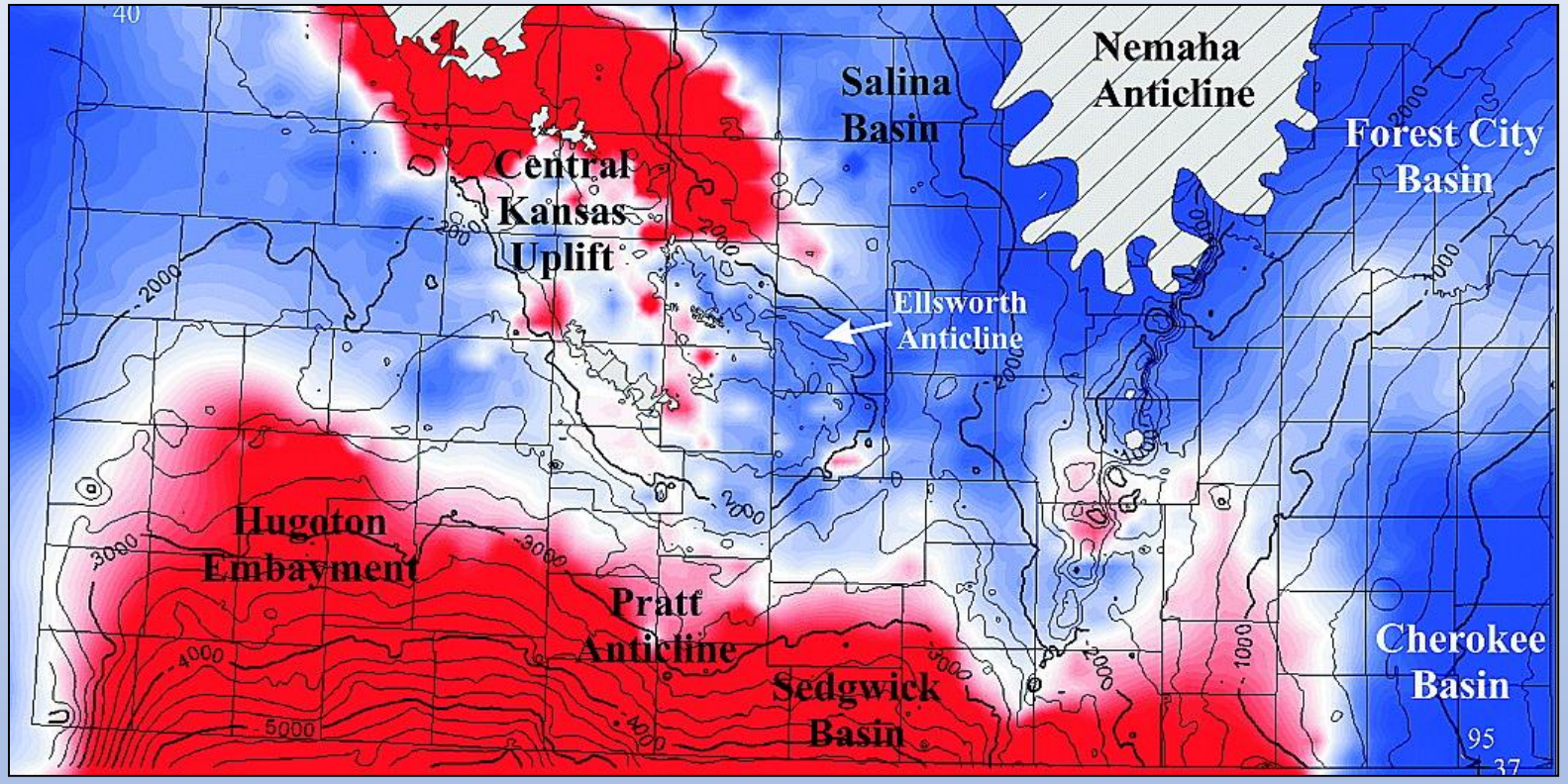
fluid injection (with hydraulic connectivity) increases pore pressure

Hydrostatic Head in Arbuckle



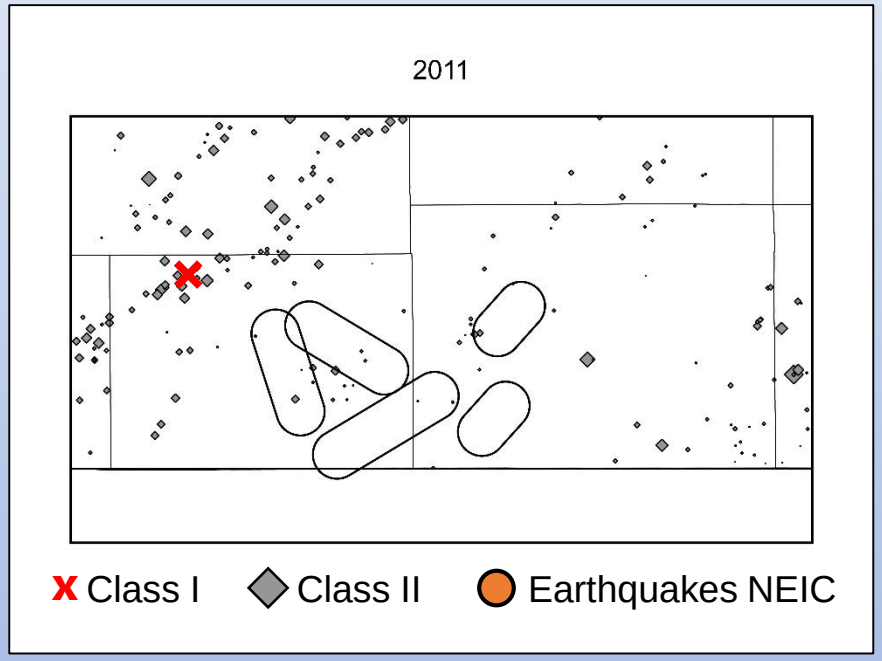
from Jorgensen and others (1993)

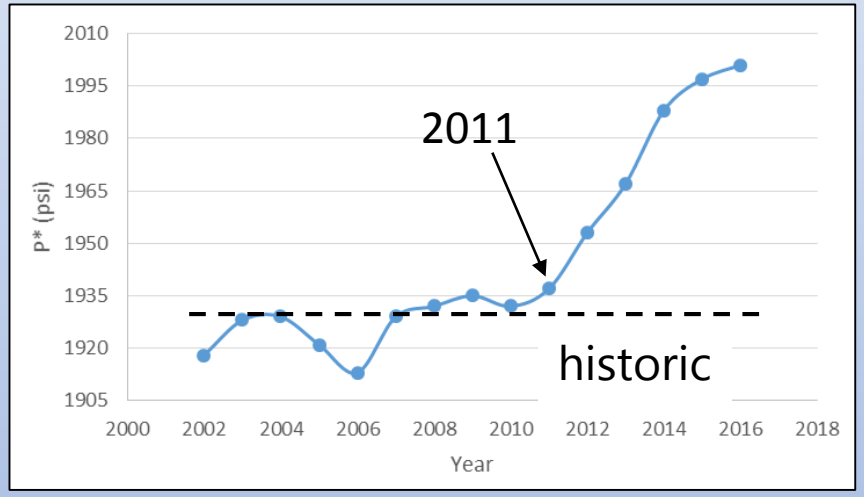
Salinity of Arbuckle Group



low **salinity** high

Pressure in Harper County



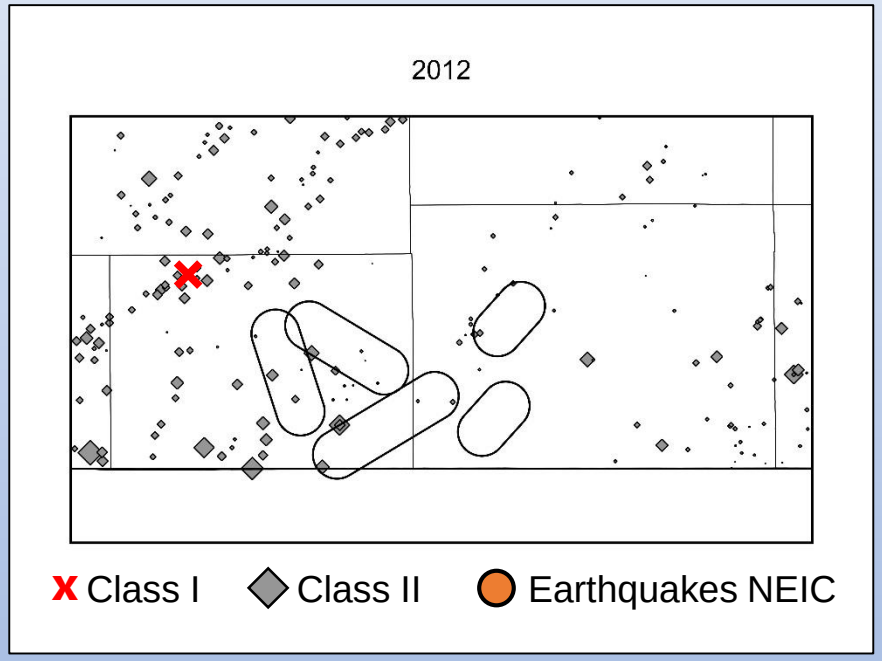


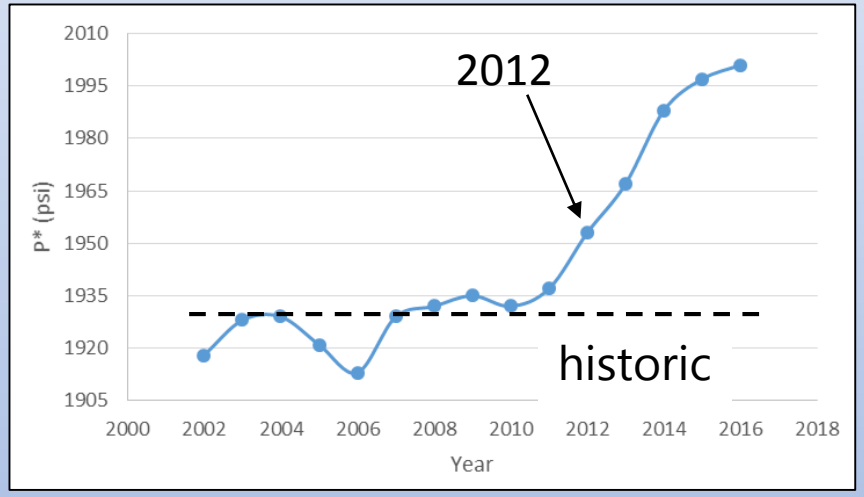
annual SWD volume (MBBL)

< 0.5

8.0

Pressure in Harper County



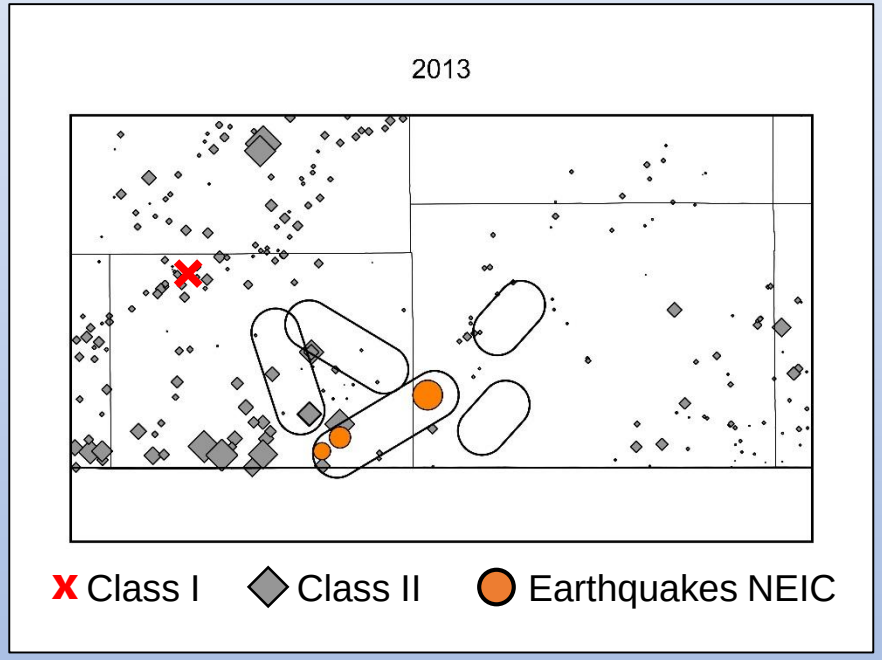


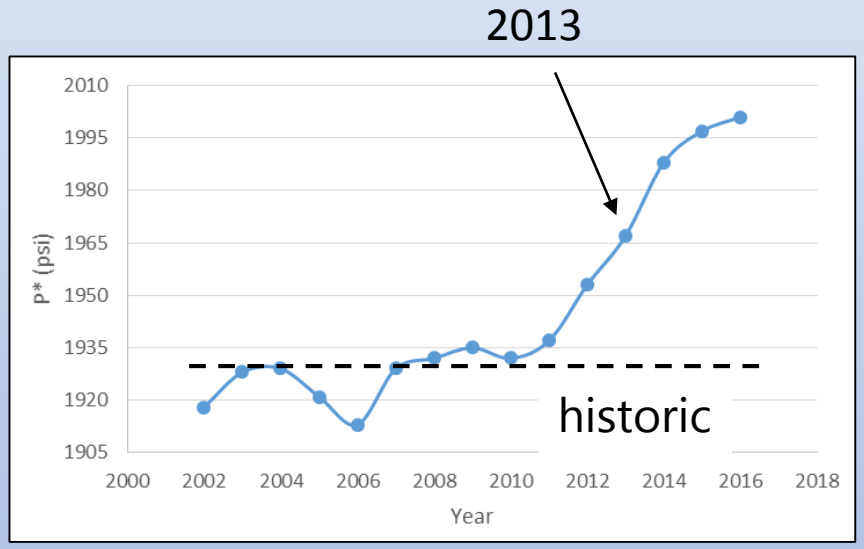
annual SWD volume (MBBL)

< 0.5

8.0

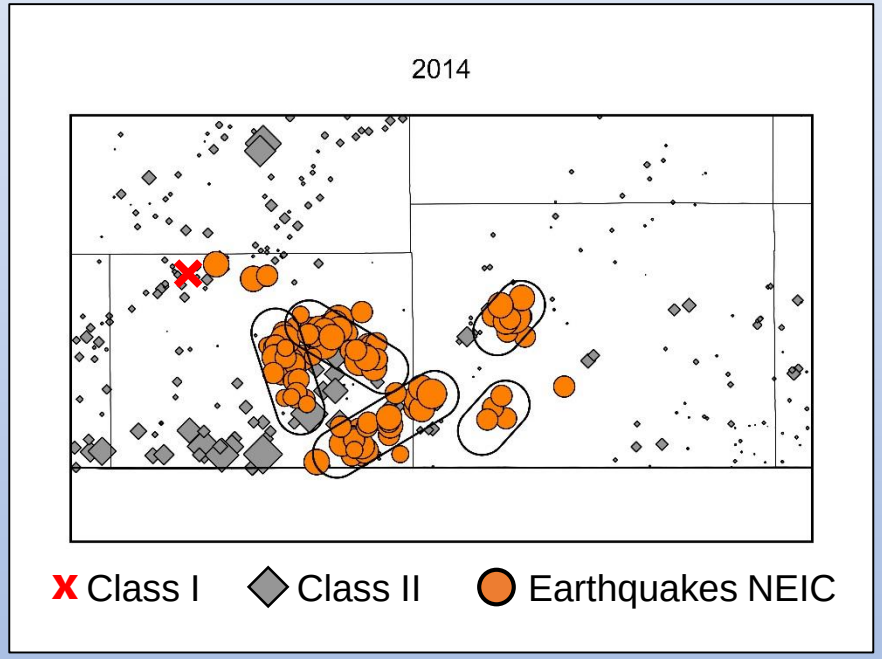
Pressure in Harper County

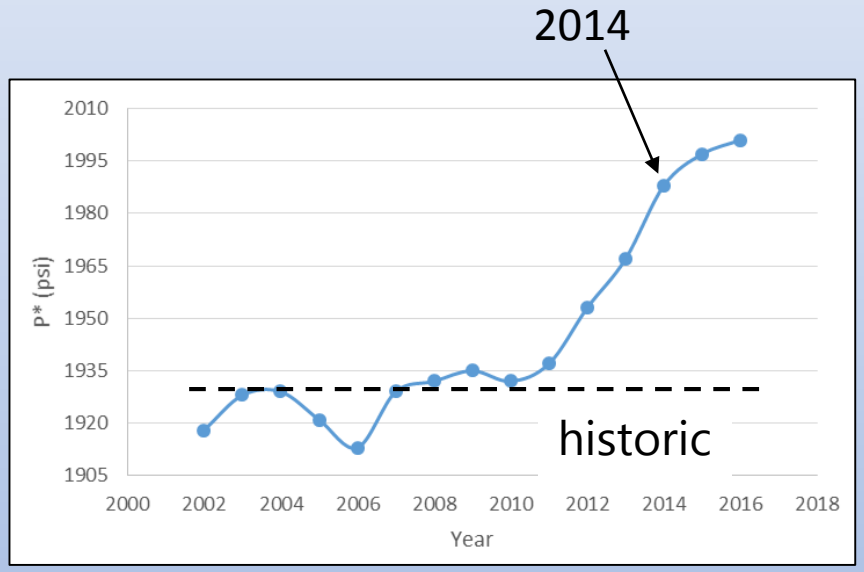




annual SWD volume (MBBL) < 0.5 8.0

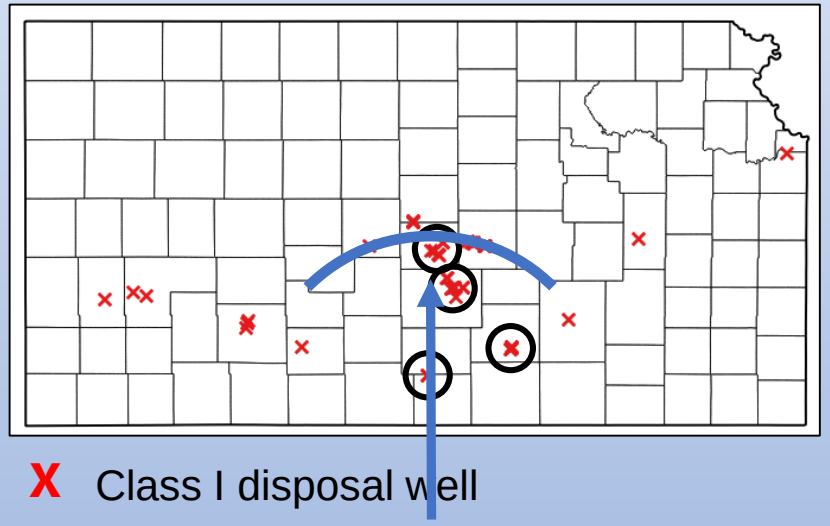
Pressure in Harper County

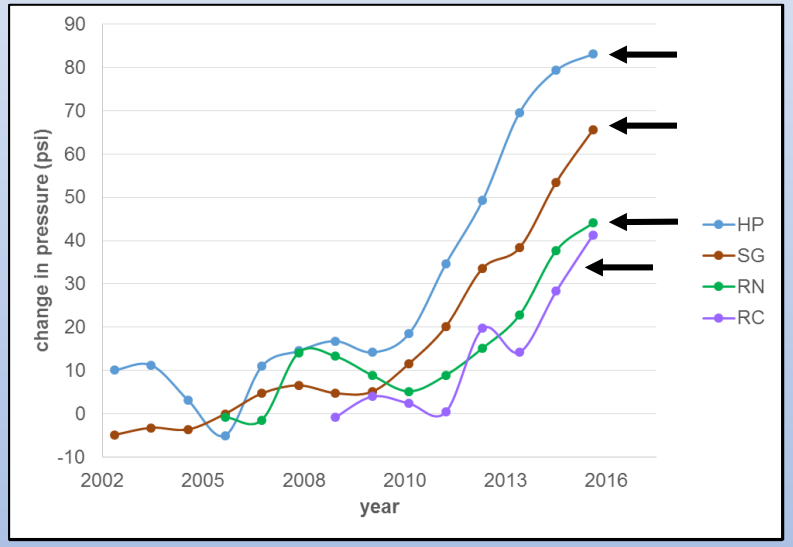




annual SWD volume (MBBL) < 0.5 8.0

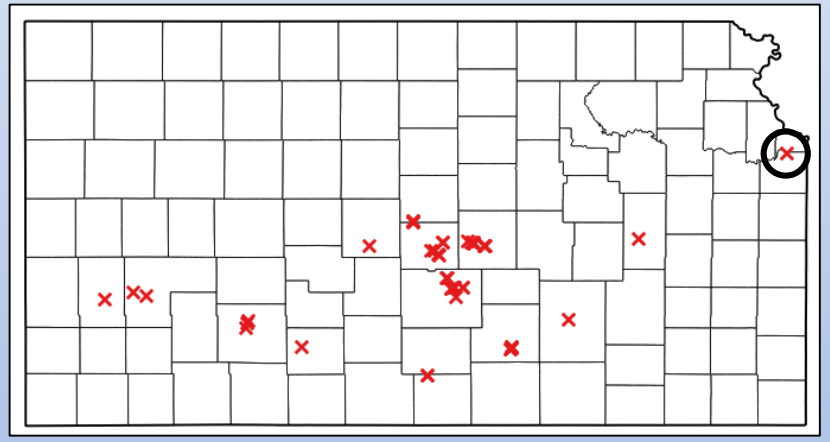
Pressure Trends Across Kansas





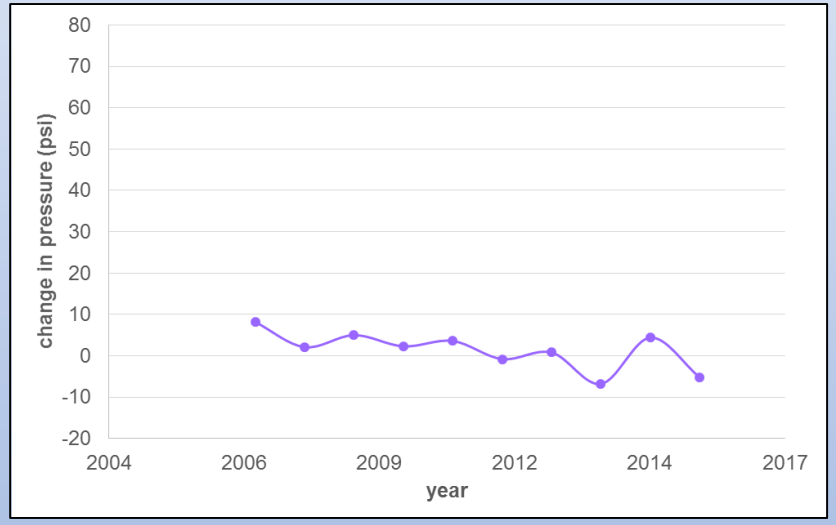
Additional Pressure Trends

Johnson County



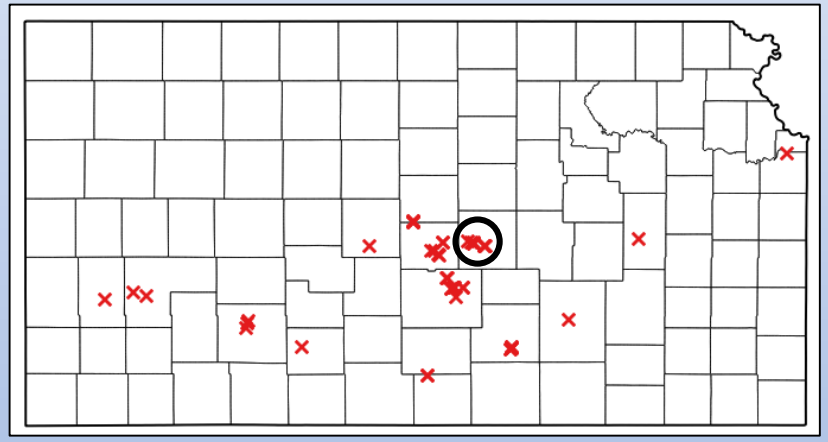
X Class I disposal well

pressure



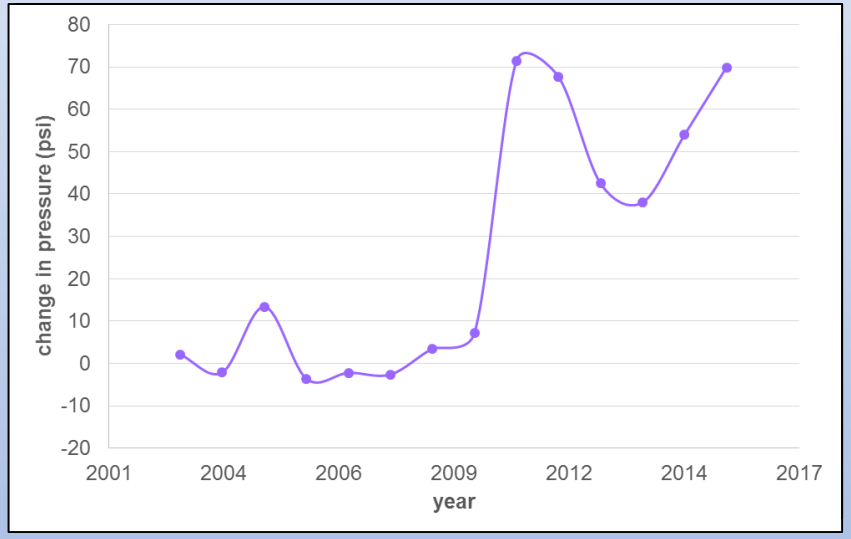
Additional Pressure Trends

McPherson County



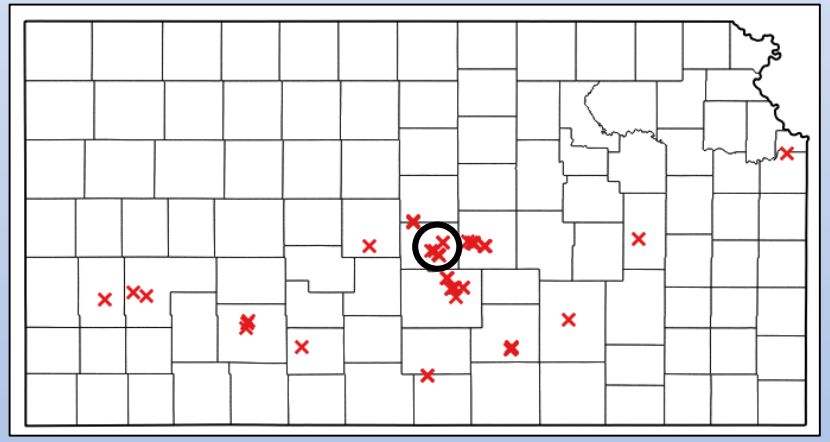
X Class I disposal well

pressure



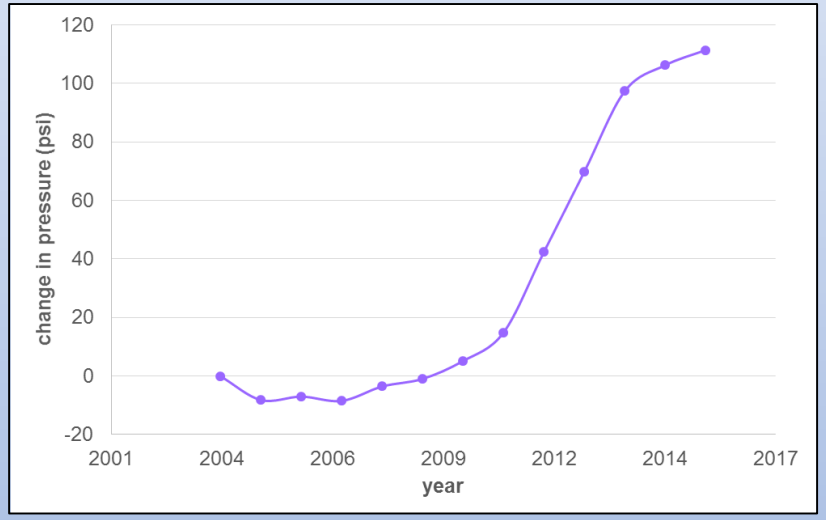
Additional Pressure Trends

Rice County



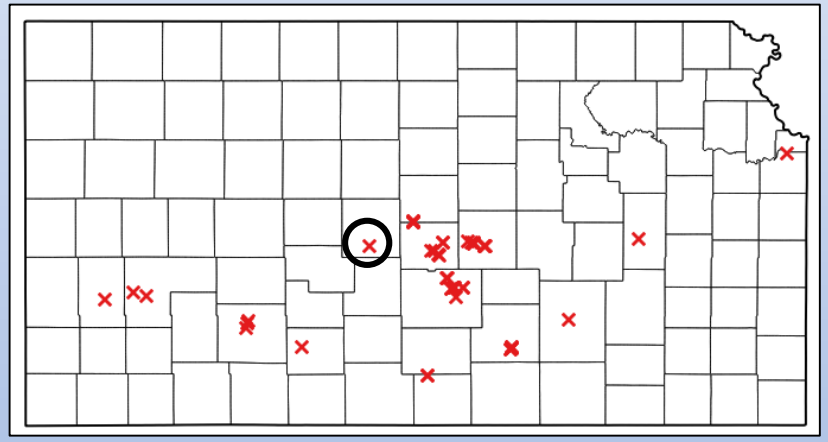
X Class I disposal well

pressure



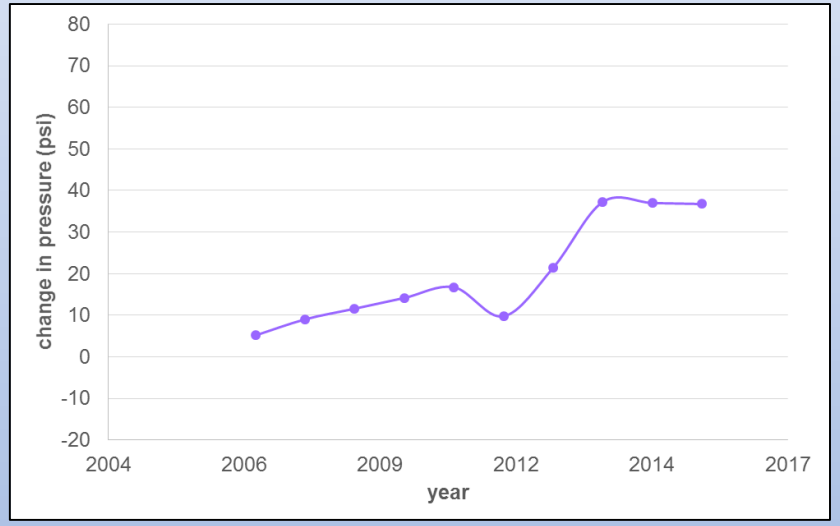
Additional Pressure Trends

Barton County



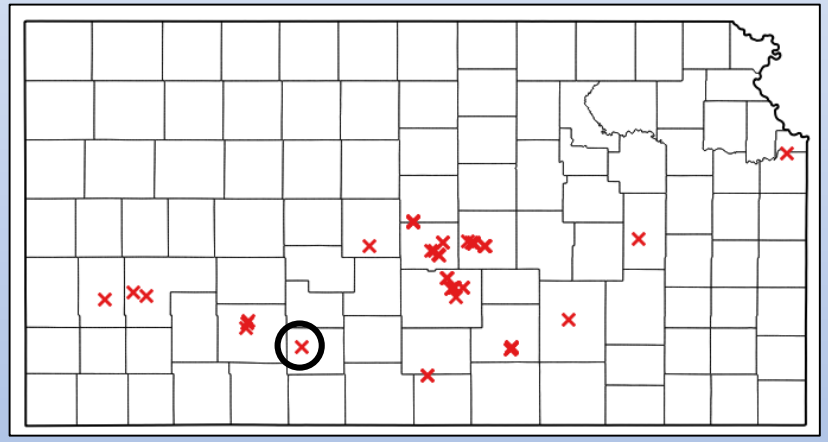
X Class I disposal well

pressure



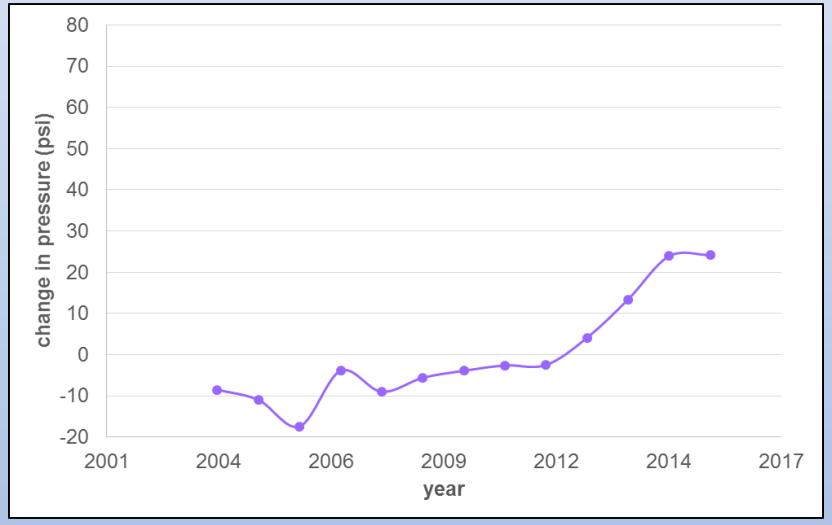
Additional Pressure Trends

Kiowa County



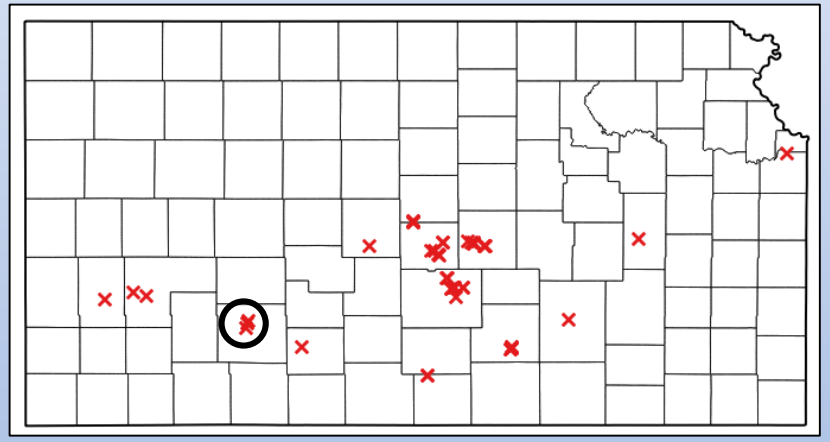
X Class I disposal well

pressure



Additional Pressure Trends

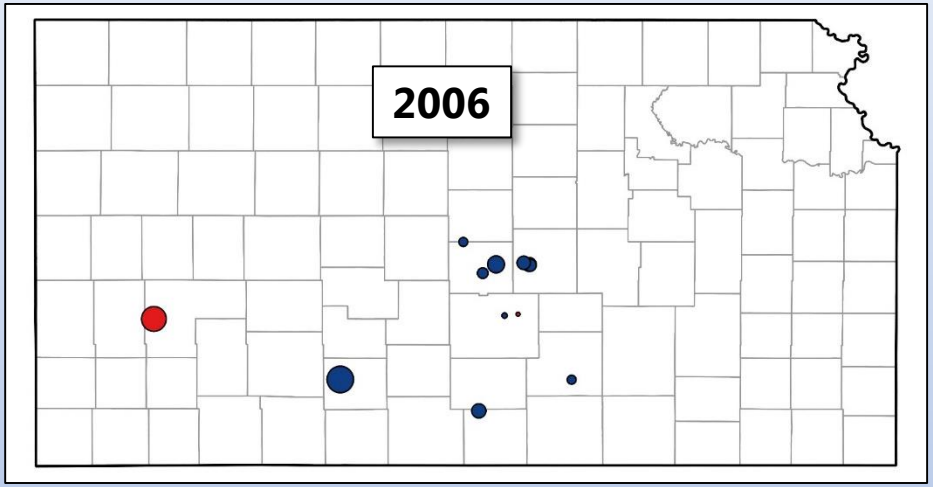
Ford County

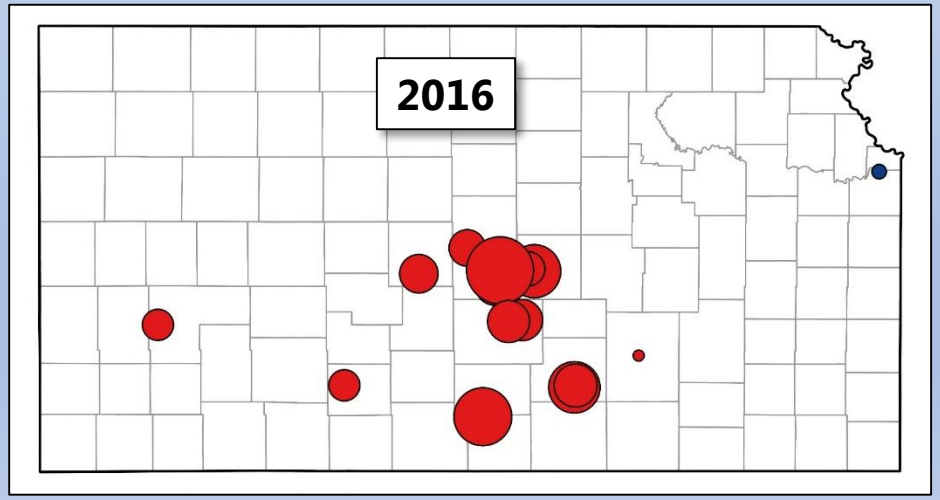


X Class I disposal well

static fluid level

Statewide Pressure Change



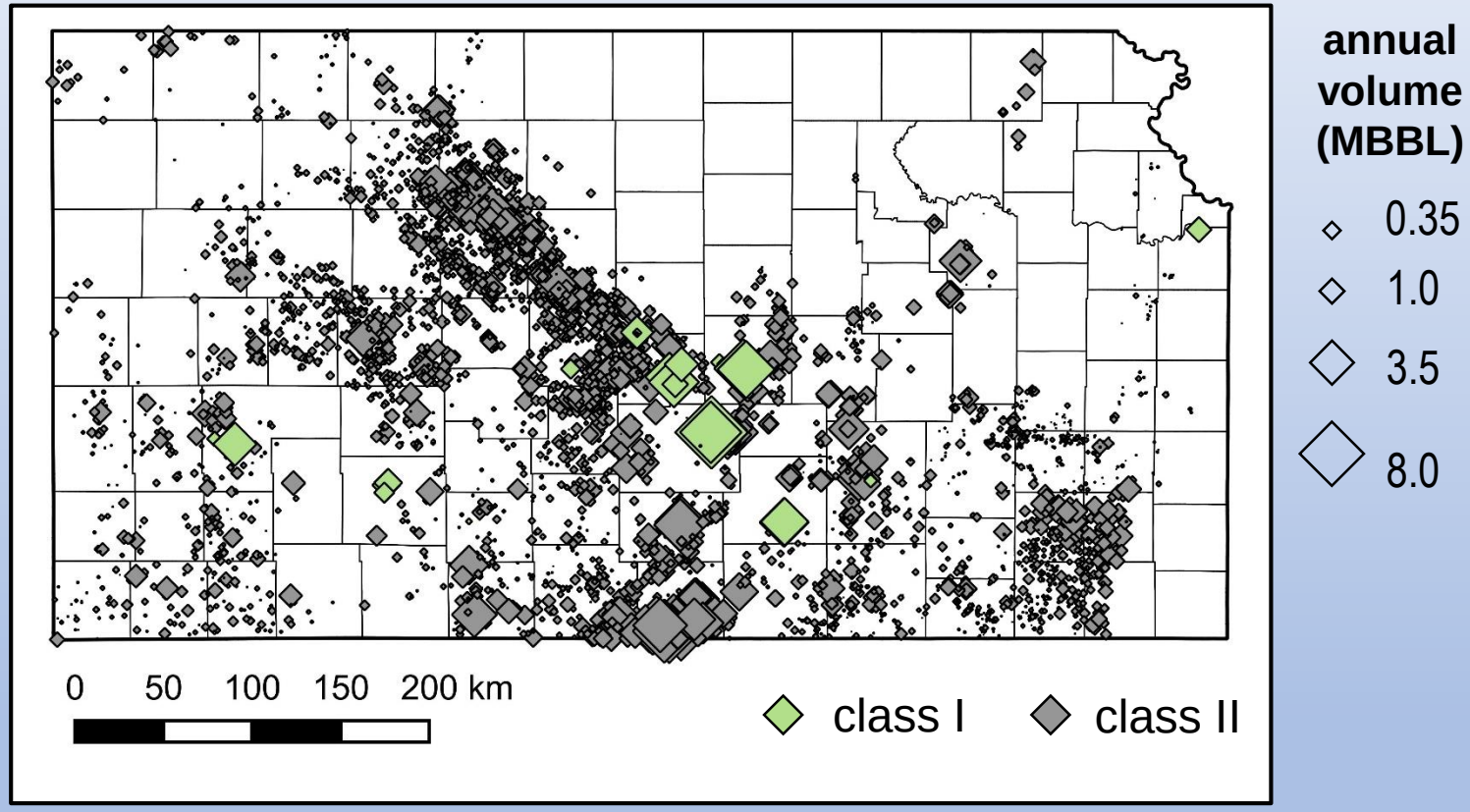


pressure change (from historic)

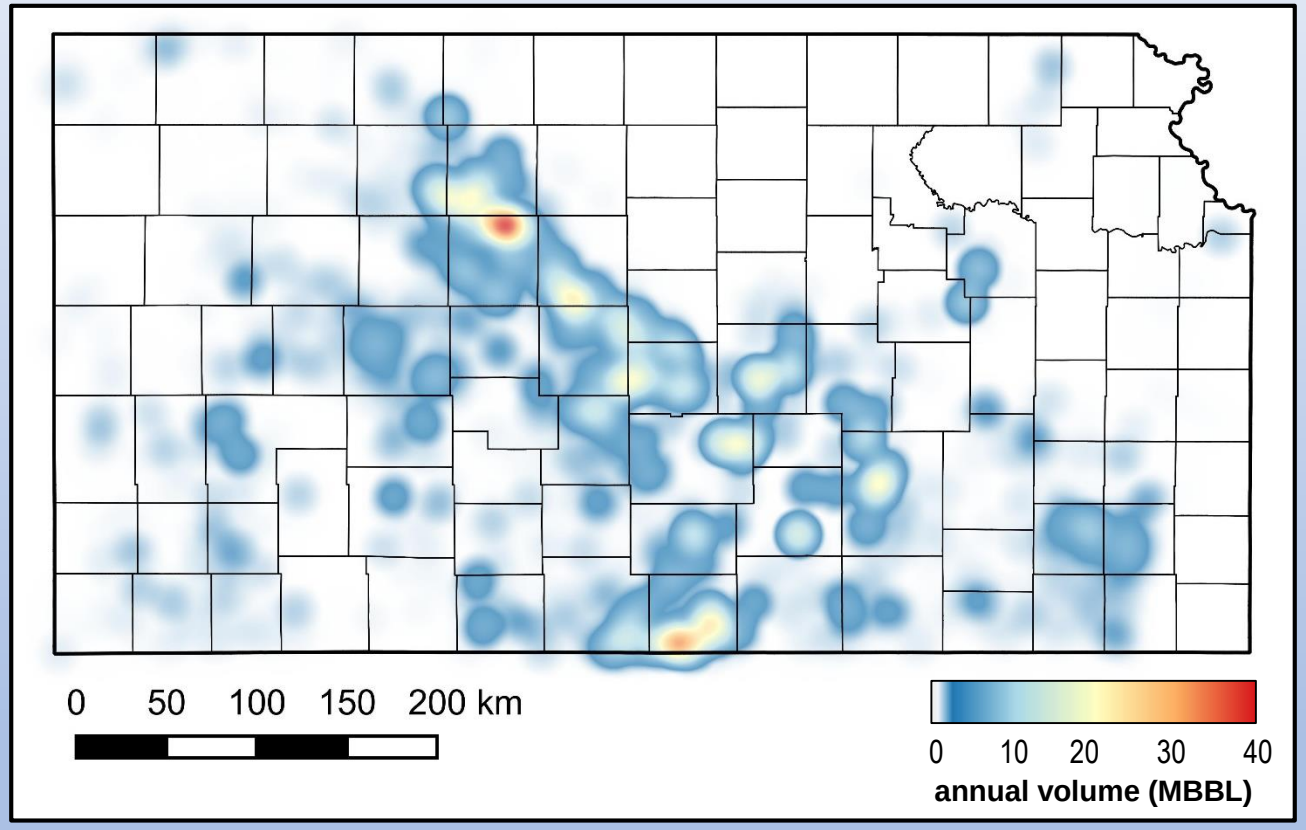
- decrease
- increase

- 2 psi
- 25 psi
- 50 psi
- 75 psi
- 100 psi

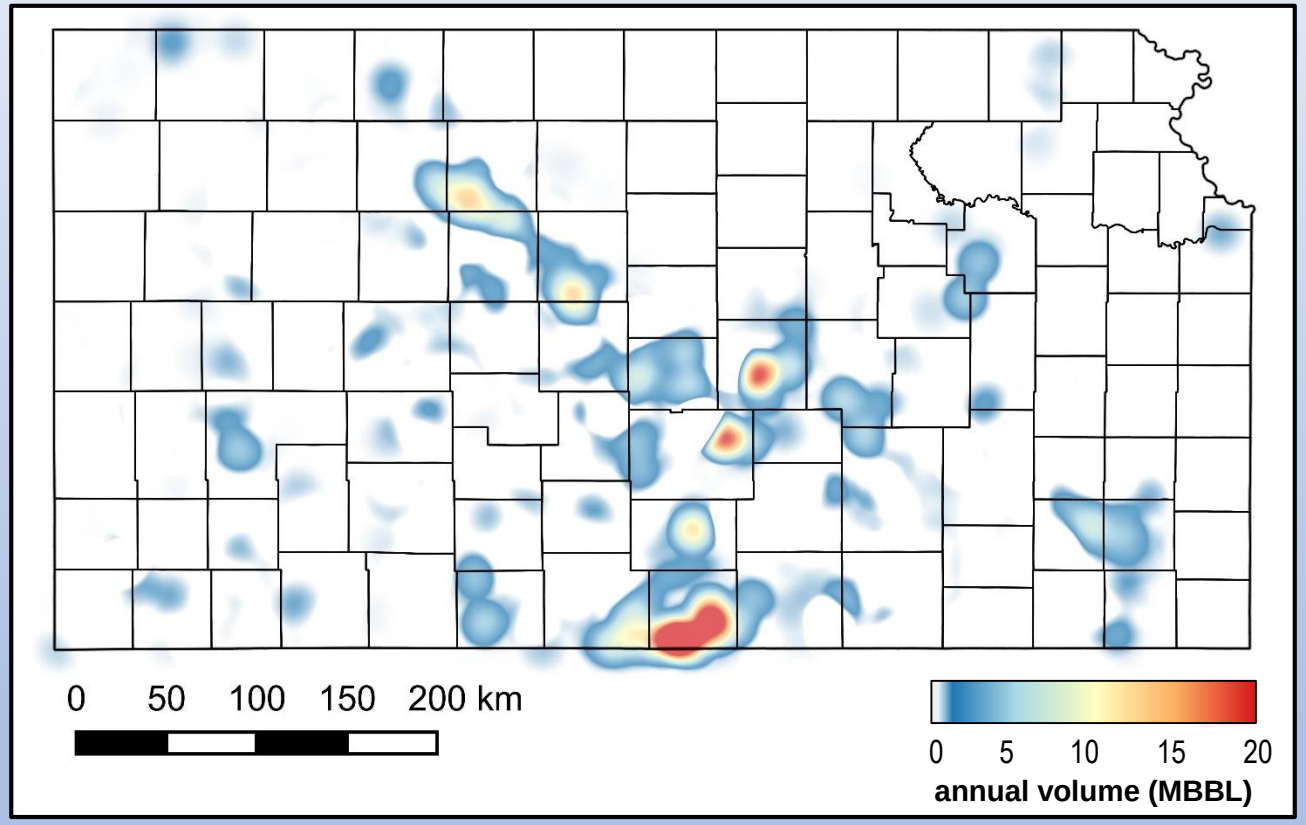
Statewide Injection 2015



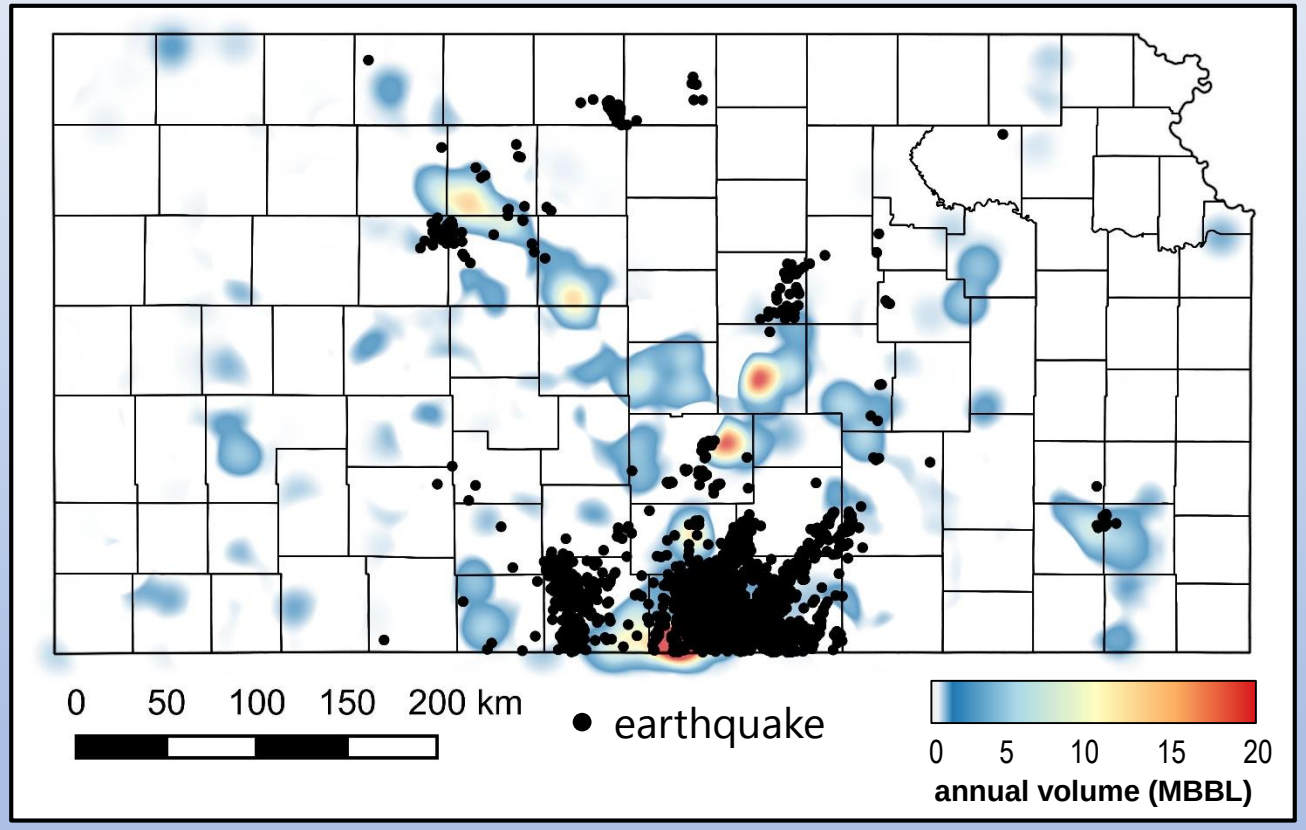
Combined Statewide Injection 2015



Change in Injection Volume



KGS Earthquakes 2015-Present

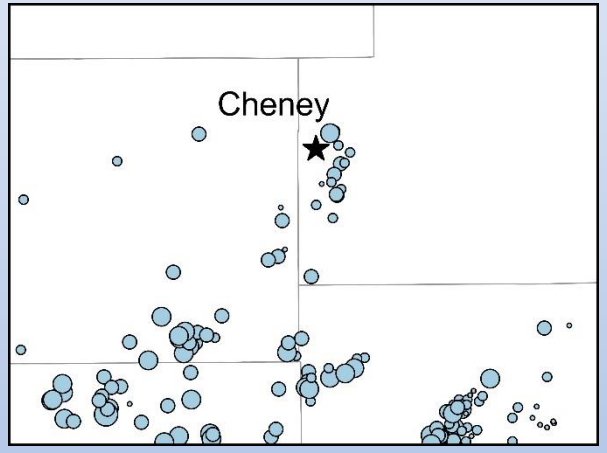


Utility of Microearthquakes

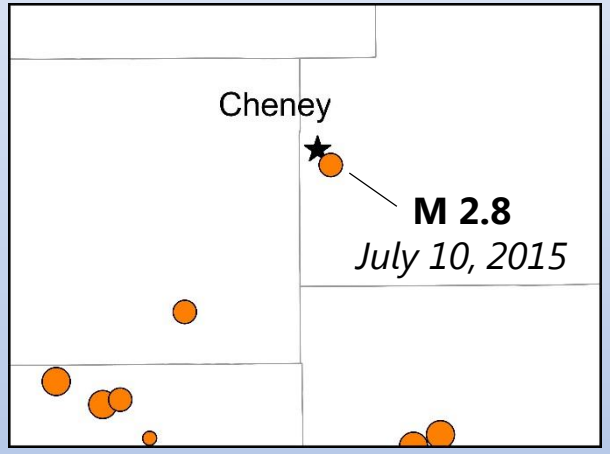
Cheney

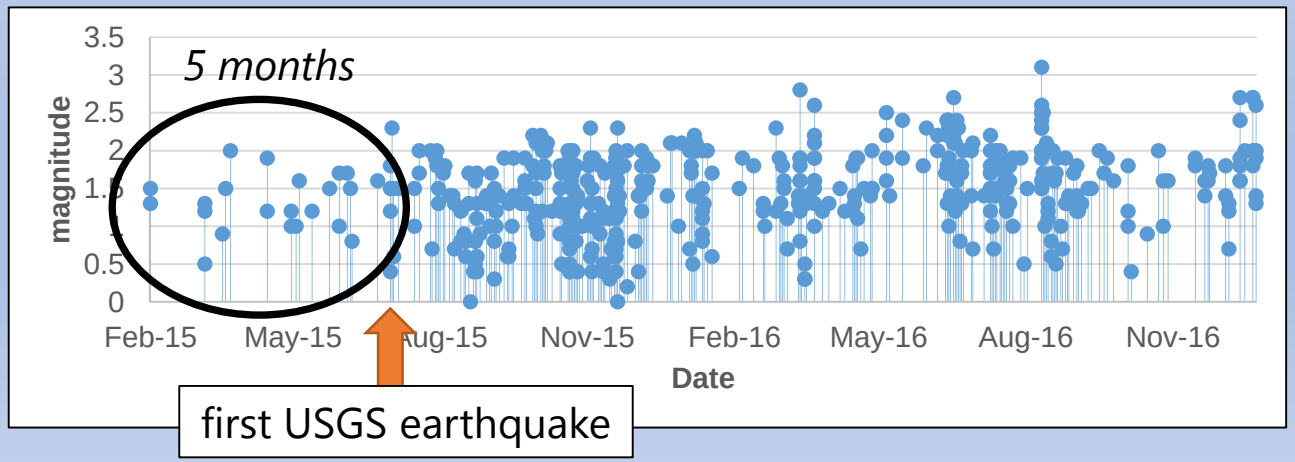
January 1 to July 10, 2015

KGS (21) M≥0.4



USGS (1)

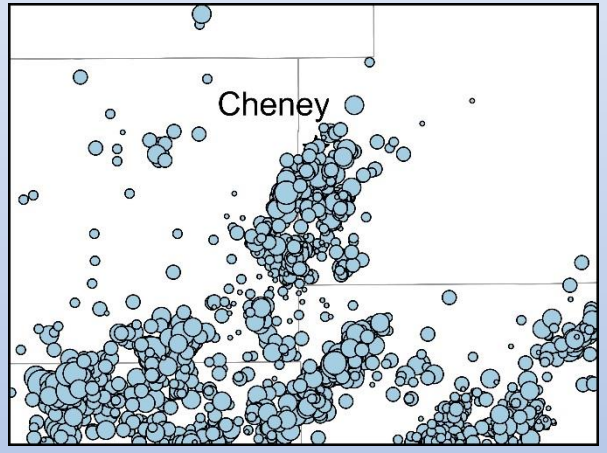




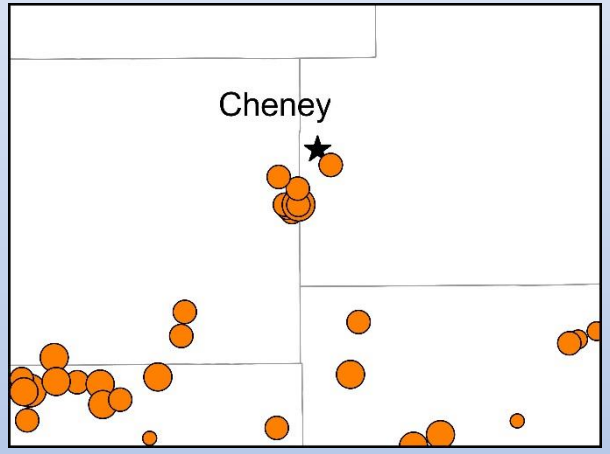
Cheney

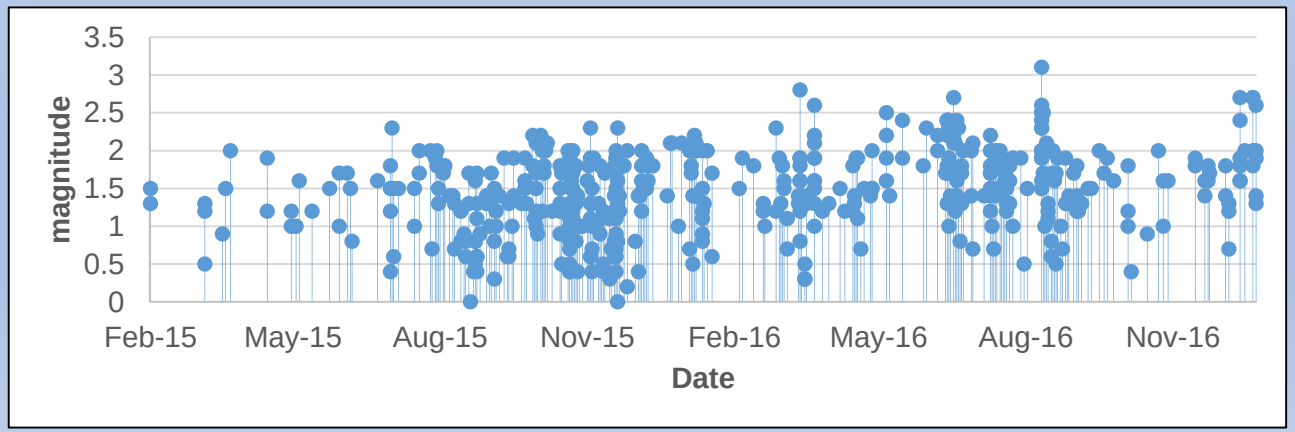
January 2015 to December 2016

KGS (486) M≥0.4

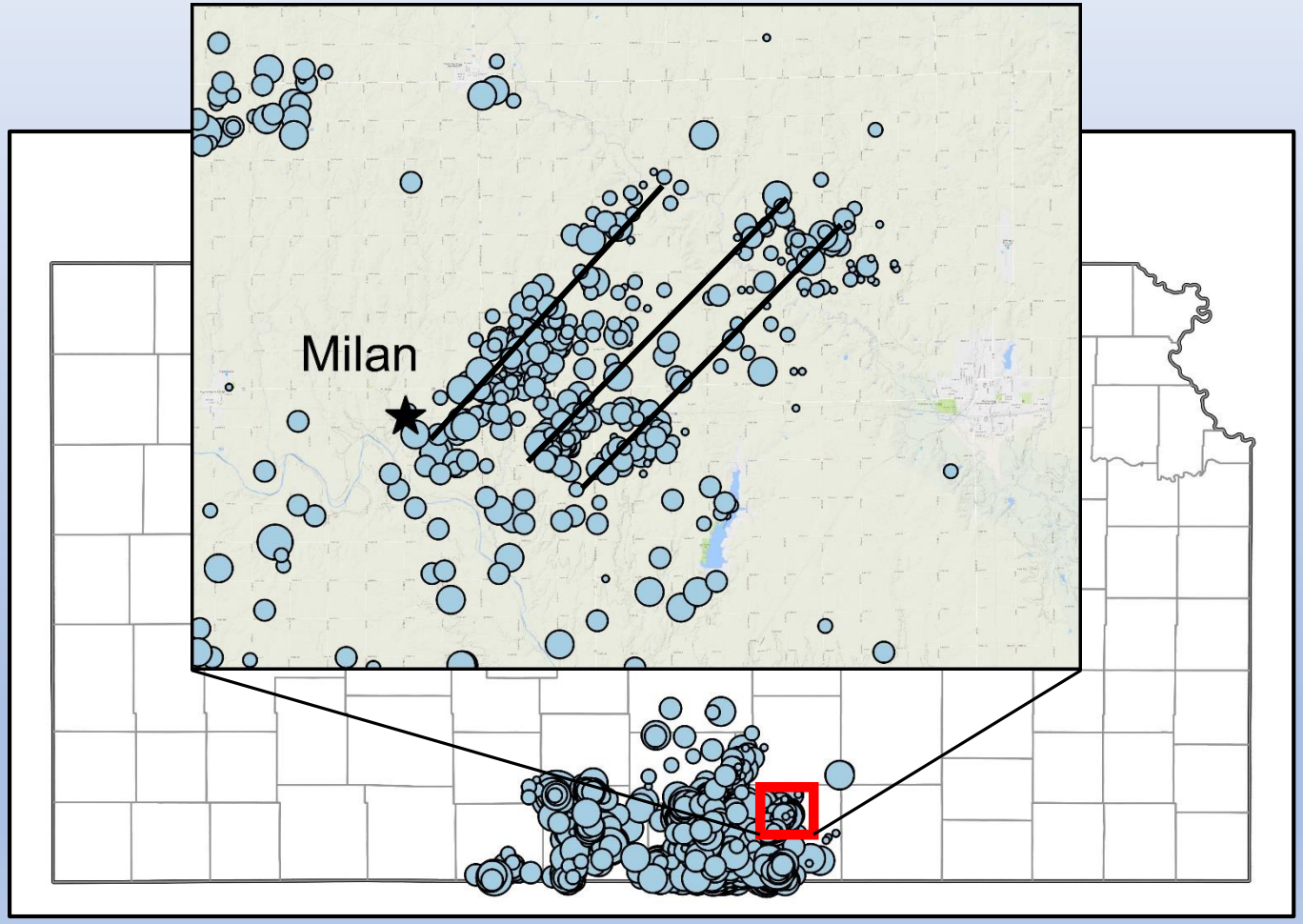


USGS (8) M≥2.4

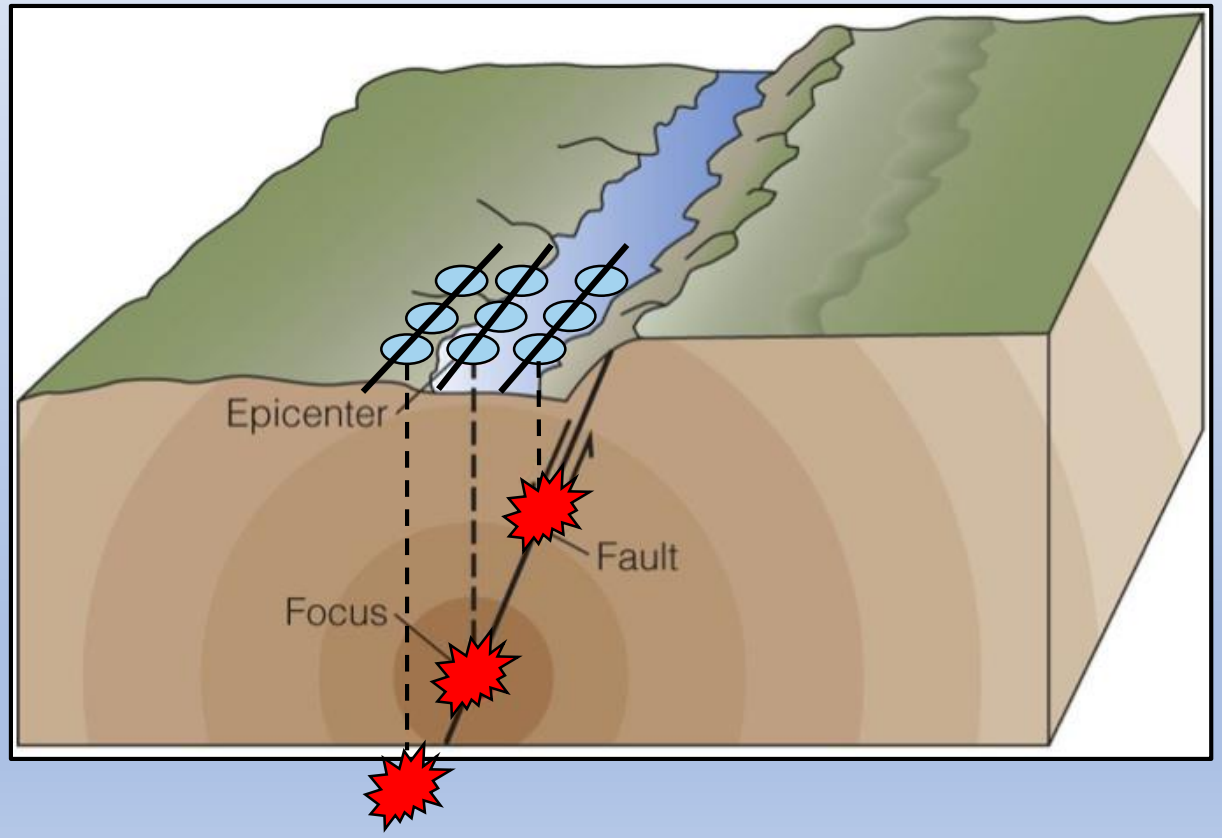




Milan



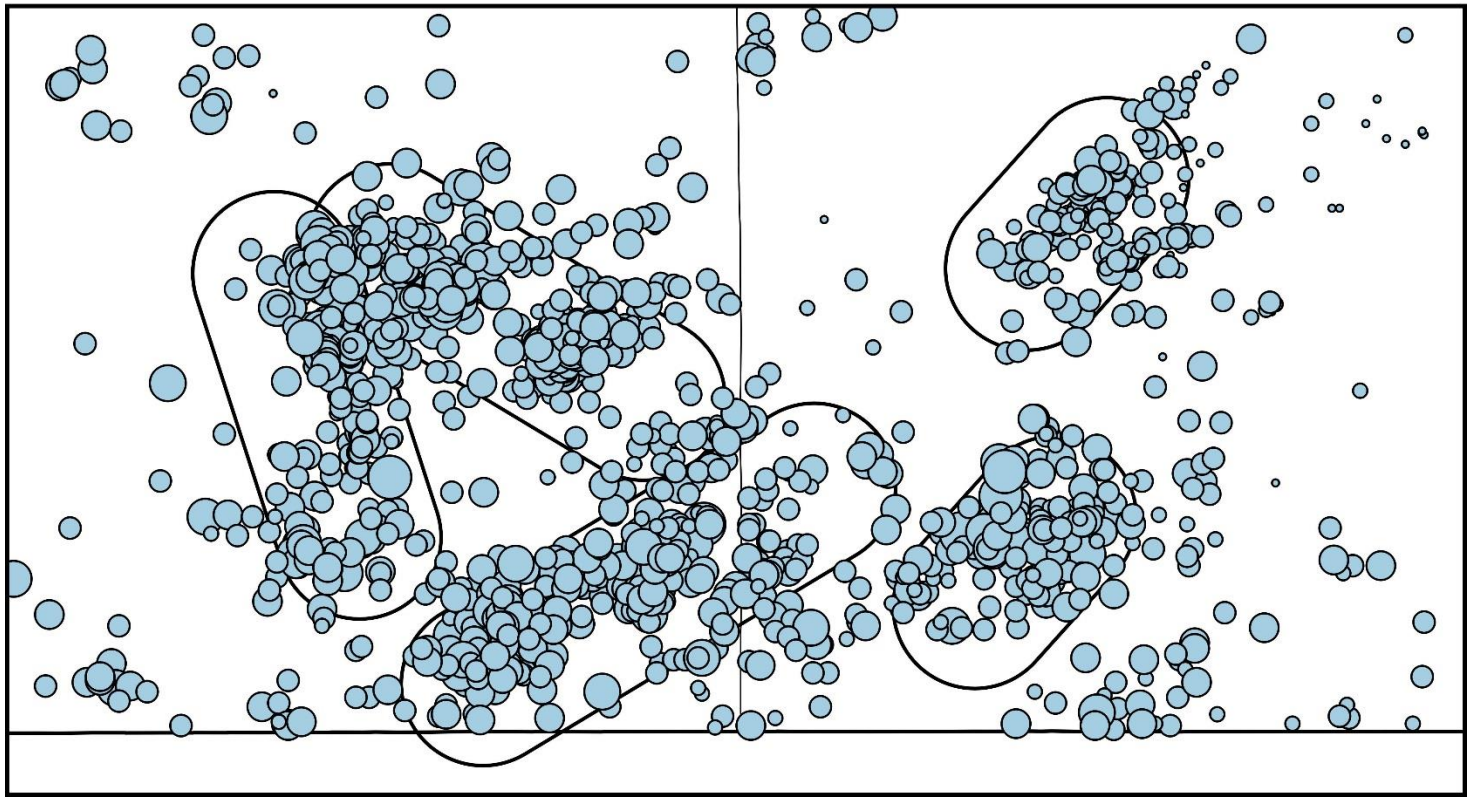
Epicenter Change with Depth



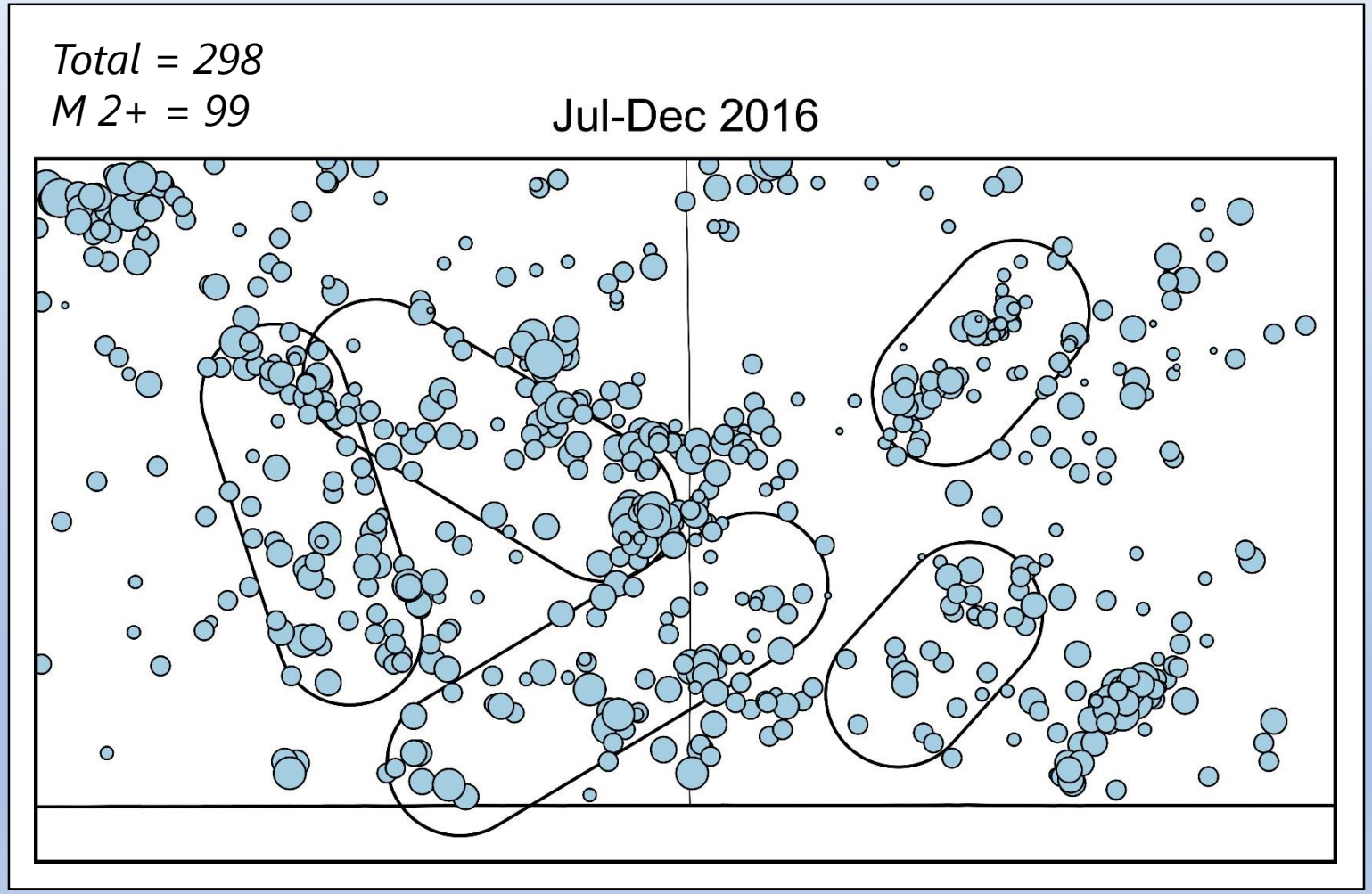
Harper & Sumner Co.

Total = 1195
M 2+ = 439

Jan-Jun 2015

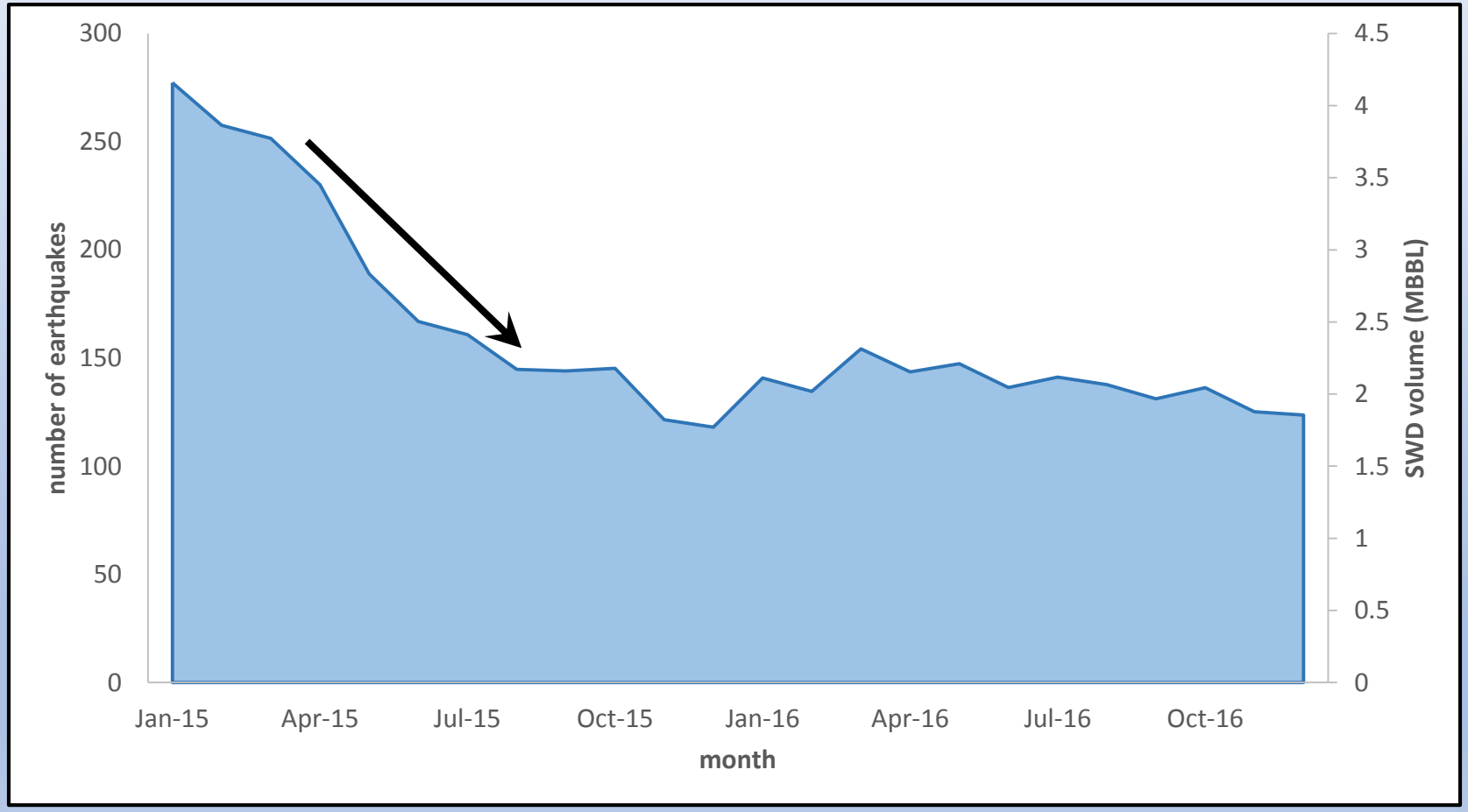


Harper & Sumner Co.



Harper & Sumner Co.

monthly SWD volume



Harper & Sumner Co.

monthly # of earthquakes