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
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**Focus areas**
  Epicenter maps
  Regional injection

Individual wells (15mi)
  Epicentral distance maps
  Injection & micro-earthquakes

Synthesis & Discussion

Website
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  Live feeds
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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
Seismic Station Installation
Seismic Station Installation

cell antenna
GPS antenna
solar panel

equipment box
Seismic Station Installation
Seismic Station Installation

charge controller

cell modem
digitizer
batteries
## Annual Cost

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<th>Tier 2 annual cost</th>
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<td>annual maintenance</td>
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<td>analyst</td>
<td>$ 2,500</td>
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<td><strong>total</strong></td>
<td><strong>$ 4,000</strong></td>
<td><strong>$ 5,000</strong></td>
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## Single Station Cost

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<th>one-time cost</th>
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<td>$ 5,000</td>
</tr>
<tr>
<td>digitizer</td>
<td>$ 6,000</td>
</tr>
<tr>
<td>cell modem, antenna, cable</td>
<td>$ 1,000</td>
</tr>
<tr>
<td>Solar panel, mounting bracket, batteries, charge controller, wiring</td>
<td>$ 1,500</td>
</tr>
<tr>
<td>GPS antenna and cable</td>
<td>$ 500</td>
</tr>
<tr>
<td>enclosure, conduit, concrete, pole, gravel</td>
<td>$ 1,000</td>
</tr>
<tr>
<td>installation</td>
<td>$ 2,000</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>$ 17,000</strong></td>
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Network Design and Site Selection
Current KGS Network

- KGS/KCC temporary station
- KGS permanent 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)
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**
- **close stations**
- **distant stations**

M 1

M 2

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

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

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
〇 15 mi radius
Minimum Member Design

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<td>2</td>
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- X class I well
- ▲ KGS seismic station
- ▲ Consortium station
Minimum Member Design

M 2–2.5 (150 km)

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

X class I well

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Minimum Member Design

M 0.5-1 (35 km)

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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
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Things to Avoid

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- Noise
  - traffic
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  - pump jacks, etc.
- Poor drainage
Example Wind Noise

quiet day

extreme wind

25-45 mph
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*electrical noise*
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Things to Avoid

• Trees
• Noise
  – traffic
  – power lines
  – pump jacks, etc.
• Poor drainage
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
Earthquake Wavetrain

vertical

north

east

$P$  $S$  coda

time (s)
Earthquake Wavetrain

45 km from epicenter

vertical
north
east

5 sec

65 km from epicenter

vertical
north
east

8 sec
Oklahoma Earthquake

M 5.8

September 3, 2016 – Pawnee
Oklahoma Earthquake

M 5.8
September 3, 2016 – Pawnee

P-wave
several minutes = large
S-wave
Kansas Earthquake

M 2.0

January 1, 2016 – Harper Co.
Kansas Earthquake

M 2.0
January 1, 2016 – Harper Co.

P-wave
Δt = 5 s
d > 40 km

S-wave
Kansas Earthquake

M 1.5

Locating Earthquakes

detected at 1 station

seismic data

triangulate

P-S time

magnitude from coda

epicentral distance

earthquake epicenter
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)
- class I well
Potentially Induced Seismicity

- **earthquake** 2013-2014
- **class II SWD**

![Graph showing potentially induced seismicity](image)

- **M3+ earthquake**
- **annual SWD volume**

---

75
KGS Network: 2015-Present

>8000 earthquakes
M 0 to 3.7
30 counties
75 % in HP & SU
KGS Network: 2015-Present
Recent Trends: Sedgwick/Butler

Historic (1977-2012)

KGS (89) – 31 M≥2

USGS (3)

first USGS earthquake
Recent Trends: Saline/McPherson

Historic (1977-2012)

KGS (46) – 21 M≥2

USGS (3)

M 1.7
1981

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

- Central KS Uplift
- MGA
- Nemaha Ridge
Earthquakes Along Structures
Trends in Fluid Level, Pressure & Injection
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
Pressure in Harper County

annual SWD volume (MBBL) < 0.5

historic

2011

x Class I  ● Class II  ● Earthquakes NEIC
Pressure in Harper County

annual SWD volume (MBBL)
< 0.5  
8.0
Pressure in Harper County

2013

2013

historic

annual SWD volume (MBBL)

< 0.5

8.0

x Class I

Class II

Earthquakes NEIC

X Class I

Class II

Earthquakes NEIC

2010 2012 2014 2016 2018

P* (psig)

2010 2012 2014 2016 2018

Year
Pressure in Harper County

annual SWD volume (MBBL) < 0.5  8.0

historical graph showing data fluctuations over years.
Pressure Trends Across Kansas

X Class I disposal well
Additional Pressure Trends

Johnson County

X Class I disposal well
Additional Pressure Trends

McPherson County

X Class I disposal well

pressure
Additional Pressure Trends

*Rice County*

X Class I disposal well
Additional Pressure Trends

Barton County

X Class I disposal well

pressure

X


change in pressure (psi)

-20 0 10 20 30 40 50 60 70 80

year
Additional Pressure Trends

Kiowa County

X Class I disposal well
Additional Pressure Trends

Ford County

× 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

annual volume (MBBL)

diamond 0.35
diamond 1.0
diamond 3.5
diamond 8.0
Combined Statewide Injection 2015
Change in Injection Volume
KGS Earthquakes 2015-Present

[Map diagram showing earthquake locations and annual volume in MBBL]
Utility of Microearthquakes
Cheney

January 1 to July 10, 2015

KGS (21) M≥0.4

USGS (1)

M 2.8
July 10, 2015

5 months

first USGS earthquake
Cheney

January 2015 to December 2016

KGS (486) M≥0.4

USGS (8) M≥2.4

Date


magnitude
Milan
Epicenter Change with Depth
Harper & Sumner Co.

Total = 298
M 2+ = 99

Jul-Dec 2016
Harper & Sumner Co.

monthly SWD volume

Diagram showing the number of earthquakes and monthly SWD volume from January 2015 to October 2016.
Harper & Sumner Co.

monthly # of earthquakes

[Bar and line graph showing the number of earthquakes and SWD volume (MBBL) per month from Jan-15 to Oct-16.]