

Potential Injection-Induced Seismicity Associated With Oil & Gas Development

A primer on technical & regulatory considerations informing risk management & mitigation



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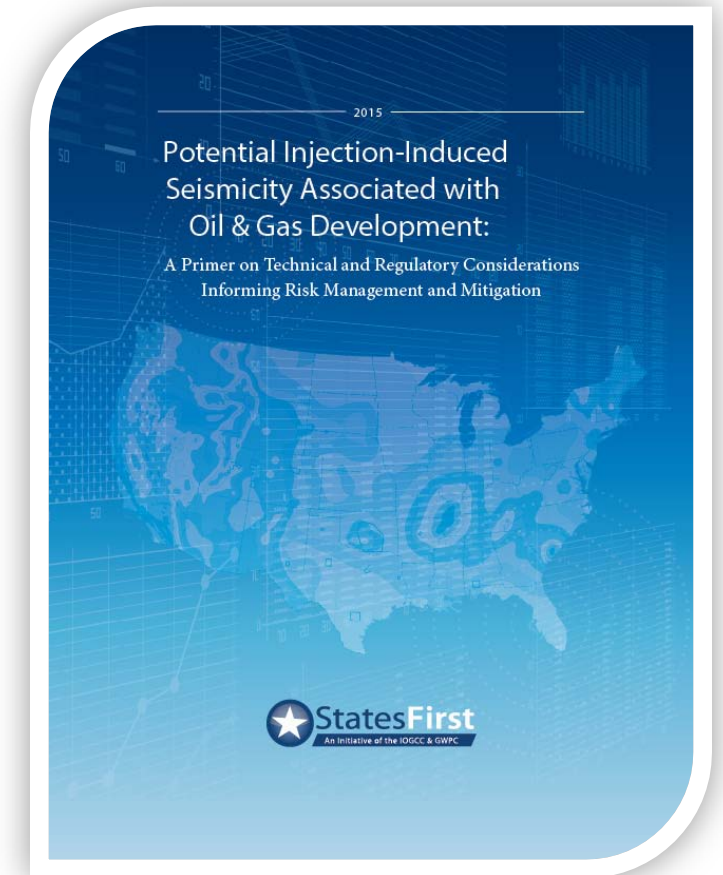
Introduction

- ▶ StatesFirst: Collaborative partnership between the Ground Water Protection Council and the Interstate Oil & Gas Compact Commission
- ▶ StatesFirst *Induced Seismicity Work Group* (“ISWG”) chartered in 2014 and led by States
- ▶ The ISWG is focused on addressing public concerns associated with induced seismicity
- ▶ Work Group deliverable: a “Primer” document to summarize and share knowledge



Primer Overview

- ▶ Primary emphasis on potential induced seismicity associated with Class II disposal wells
- ▶ Document is solely informational and is not intended to offer recommended rules or regulations



Primer Content

▶ 4 Chapters

1. Understanding induced seismicity
2. Assessing potentially induced seismicity
3. Risk management & mitigation strategies
4. External engagement & communication

▶ 9 Technical Appendices

- ❖ Relevant earthquake science
- ❖ Class II injection wells
- ❖ Induced seismicity case studies
- ❖ Design & installation of seismic monitoring networks
- ❖ NRC Report on induced seismicity potential in energy technologies
- ❖ Methods for estimating reservoir pressures changes associated with injection
- ❖ Tools for risk management and mitigation
- ❖ Data collection & interpretation
- ❖ Considerations for hydraulic fracturing

Primer Chapter 1

Understanding Induced Seismicity

Focused on:

- ▶ Magnitude and depth of induced earthquakes
- ▶ Hazard and risk of induced seismicity
- ▶ Ground motion models for induced seismicity
- ▶ USGS hazard maps
- ▶ Estimated number of induced seismicity locations
- ▶ How fluid injection may induce seismic events
- ▶ Potential for seismicity related to hydraulic fracturing
- ▶ Future research opportunities

Key Observations

- ▶ Majority of earthquakes tectonic but seismicity can be triggered by human activities
 - ❖ Induced seismic activity has been documented since at least the 1920s underground injection, oil and gas extraction, impoundment of reservoirs behind dams, geothermal projects, mining extraction, construction, underground nuclear tests, and carbon capture and storage projects
- ▶ Most cases of felt injection-induced activity have been attributed to:
 - ❖ Direct injection into basement rocks
 - ❖ Injection into overlying formations with permeable avenues of communication with basement rocks

Primer Chapter 2

Assessing Potentially Induced Seismicity

Focused on:

- ▶ Evaluating General Patterns of Seismicity
- ▶ Detection and Location
- ▶ Seismic Monitoring by States
- ▶ Evaluating Causation of Specific Seismic Events
- ▶ Methods Used in Causation Studies
- ▶ Further Analysis to Evaluate Causation

Key Observations – Evaluating Seismicity

- ▶ Three components necessary for felt injection-induced seismicity:
 - ❖ Sufficient pore pressure buildup from disposal activities
 - ❖ Faults of concern
 - ❖ A pathway allowing increased pressure to communicate with fault

- ▶ State considerations:
 - ❖ Evaluate general patterns of seismicity to reveal areas of concern
 - ❖ Perform an investigation to evaluate possible causal factors of specific events; recognizing a detailed seismological and subsurface characterization and modeling effort may be needed.

Primer Chapter 3

Risk Management and Mitigation Strategies

Key Observations

- ▶ States have developed diverse strategies for avoiding, mitigating and responding to risks of induced seismicity in siting, permitting & monitoring of Class II injection wells
- ▶ “One-Size Fits All” regulatory approach not appropriate
 - ❖ Differences in geology across US
 - ❖ Varying conditions across states

Key Observations - Risk Mitigation

- ▶ Risk mitigation options in siting and permitting new Class II disposal wells may include:
 - ❖ Avoiding injection into crystalline basement
 - ❖ Avoiding direct injection into known faults of concern
 - ❖ Locating faults in vicinity of proposed project area; place well outside “at-risk” area
- ▶ Considerations attached to permits may include:
 - ❖ Temporary seismic monitoring at sites
 - ❖ Procedure to monitor operations if ground motion event occurs
 - ❖ Procedure to suspend operations if seismicity levels increase above threshold
 - ❖ Metric to determine if operations could be re-started
- ▶ States may determine different response strategies “fit for purpose”

Primer Chapter 4

Considerations for External Communication and Engagement

Focused on:

- ▶ Communications planning process
- ▶ Communications plan elements
- ▶ Responding to an event

Key Considerations

- ▶ Clear and direct communication with public important responsibility of states
- ▶ Many states choose proactive approach
- ▶ Earthquakes arrive without warning and are unpredictable
- ▶ Most of US has no public training on what to expect from earthquakes
- ▶ Public anxiety
- ▶ Determining cause is very difficult in most instances, and studies take time

In Conclusion

- ▶ Induced seismicity is a very complex issue where the base of knowledge is changing rapidly.
- ▶ State regulatory agencies that deal with potential injection induced seismicity should be prepared to use tools, knowledge, and expertise, many of which are offered in this document, to prepare for and respond to occurrences of induced seismicity.
- ▶ Risk management, risk mitigation, and response strategies are most effective when developed considering specific local conditions and situations

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Navigate to “Programs” on the top bar

Select “Induced Seismicity Workgroup” in left column

Primer and related materials available for download



OWSM

OCC WELL & SEISMIC MONITORING APPLICATION

Partners:

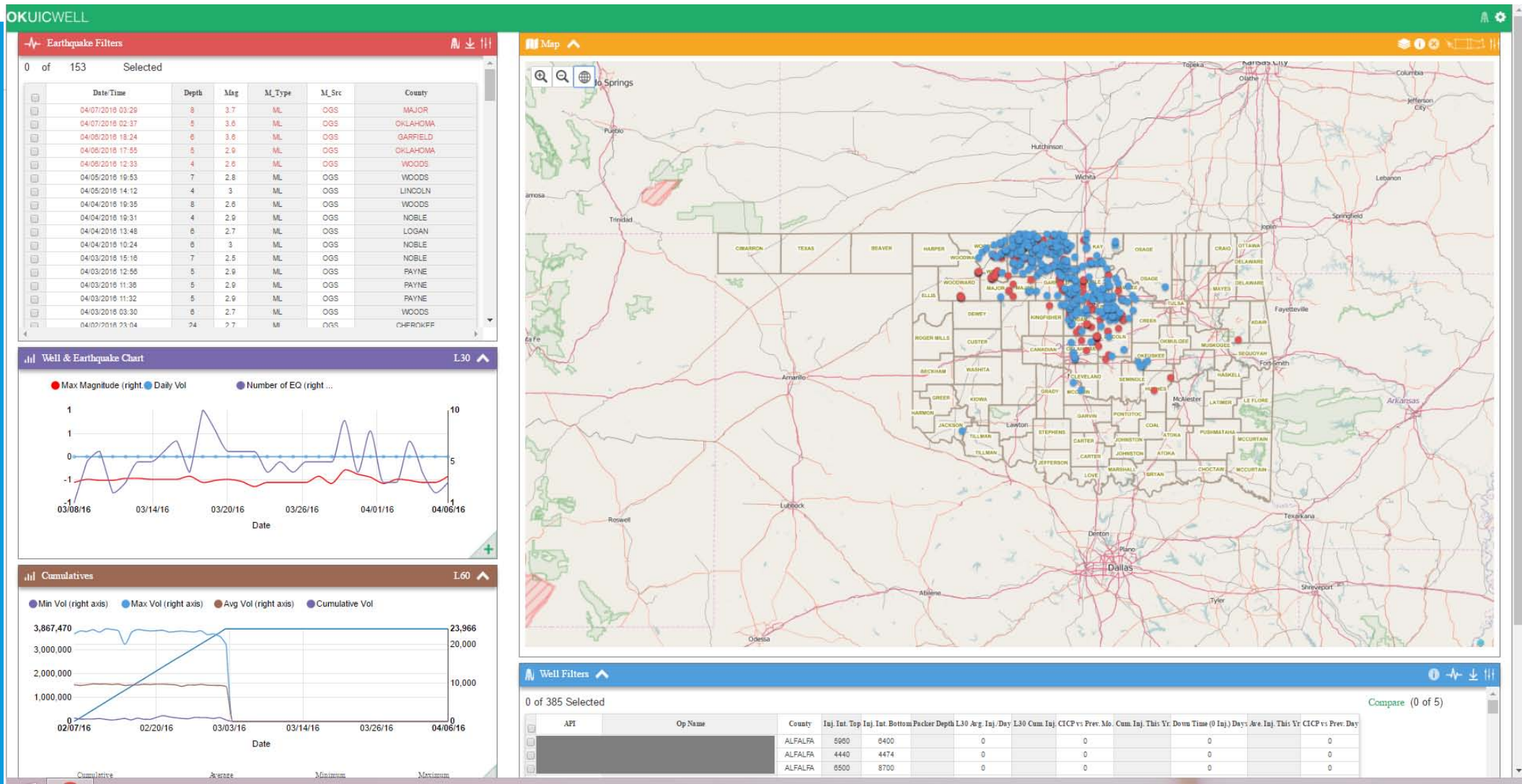
Oklahoma Energy Resourced Board

Oklahoma Corporation Commission

Ground Water Protection Council

Coordinate Solutions

OWSM – OCC WELL & SEISMIC MONITORING



SEARCH FILTERS

OKUICWELL

Earthquake Filters

0 of 153 Selected

Date/Time	Depth	Mag	M_Type	M_Src	County
<input type="checkbox"/> 04/07/2016 03:29	8	3.7	ML	OGS	MAJOR
<input type="checkbox"/> 04/07/2016 02:37	5	3.6	ML	OGS	OKLAHOMA
<input type="checkbox"/> 04/06/2016 18:24	6	3.6	ML	OGS	GARFIELD
<input type="checkbox"/> 04/06/2016 17:55	5	2.9	ML	OGS	OKLAHOMA
<input checked="" type="checkbox"/> 04/06/2016 12:33	4	2.6	ML	OGS	WOODS
<input type="checkbox"/> 04/05/2016 19:53	7	2.8	ML	OGS	WOODS
<input type="checkbox"/> 04/05/2016 14:12	4	3	ML	OGS	LINCOLN
<input type="checkbox"/> 04/04/2016 19:35	8	2.6	ML	OGS	WOODS
<input type="checkbox"/> 04/04/2016 19:31	4	2.9	ML	OGS	NOBLE
<input type="checkbox"/> 04/04/2016 13:48	6	2.7	ML	OGS	LOGAN
<input type="checkbox"/> 04/04/2016 10:24	6	3	ML	OGS	NOBLE
<input type="checkbox"/> 04/03/2016 15:16	7	2.5	ML	OGS	NOBLE
<input type="checkbox"/> 04/03/2016 12:56	5	2.9	ML	OGS	PAYNE
<input type="checkbox"/> 04/03/2016 11:36	5	2.9	ML	OGS	PAYNE
<input type="checkbox"/> 04/03/2016 11:32	5	2.9	ML	OGS	PAYNE
<input type="checkbox"/> 04/03/2016 03:30	6	2.7	ML	OGS	WOODS
<input type="checkbox"/> 04/02/2016 23:04	24	2.7	M	OGS	CHEROKEE

Well Filters

Latitude

Longitude

Address/City/State/Zip

City

County

Well Name and/or Number

Operator Name

API

Filter by Selected

Clear

Injection Interval Top

Injection Interval Bottom

Packer Depth

Permitted Max Pressure

Permitted Max Daily Rate

Cumulative Injection This Year

Down Time (zero injection volume) Day Count

Average Daily Injection This Year (only non-zero days)

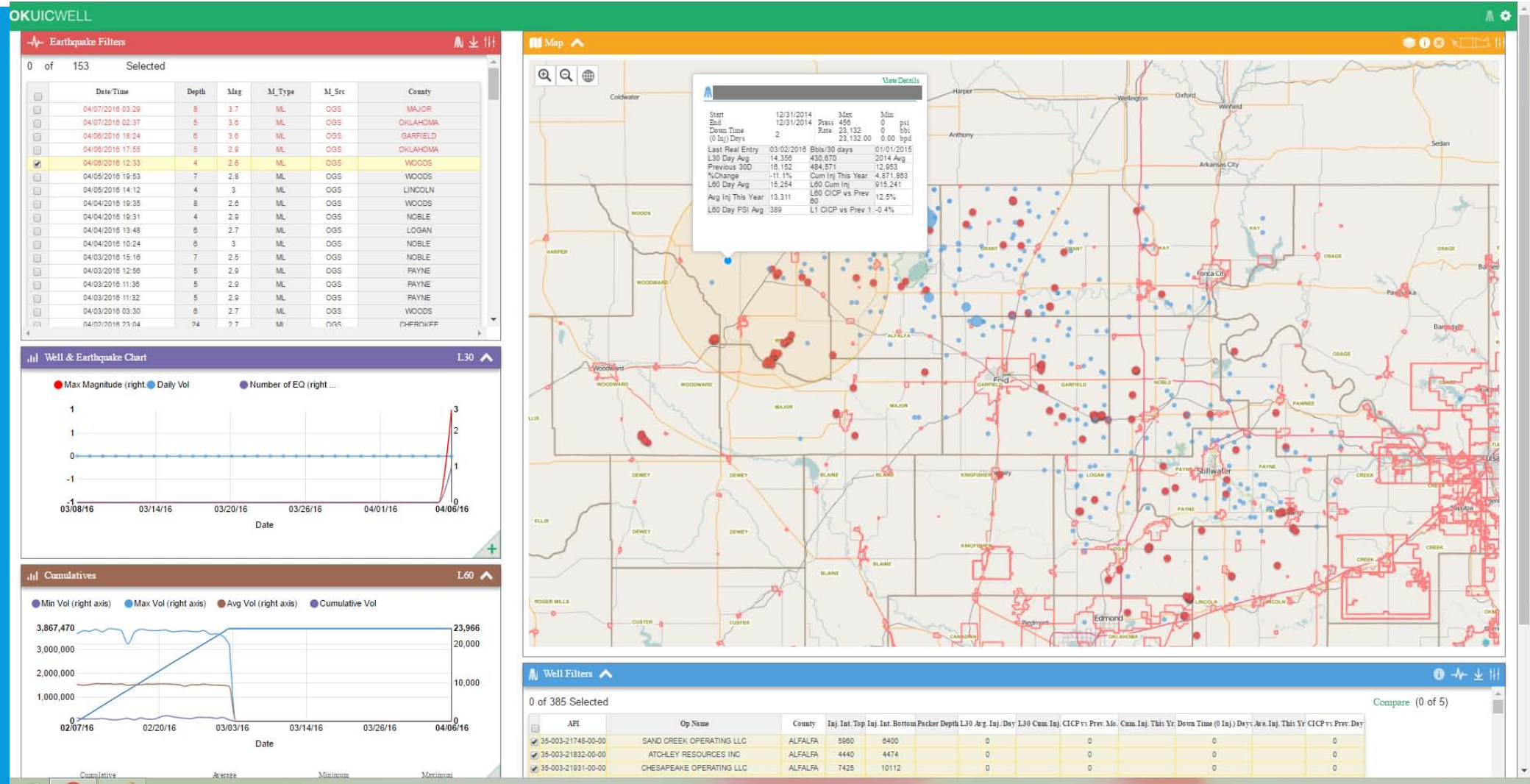
Cumulative Injection Change % vs Previous Day

Apply

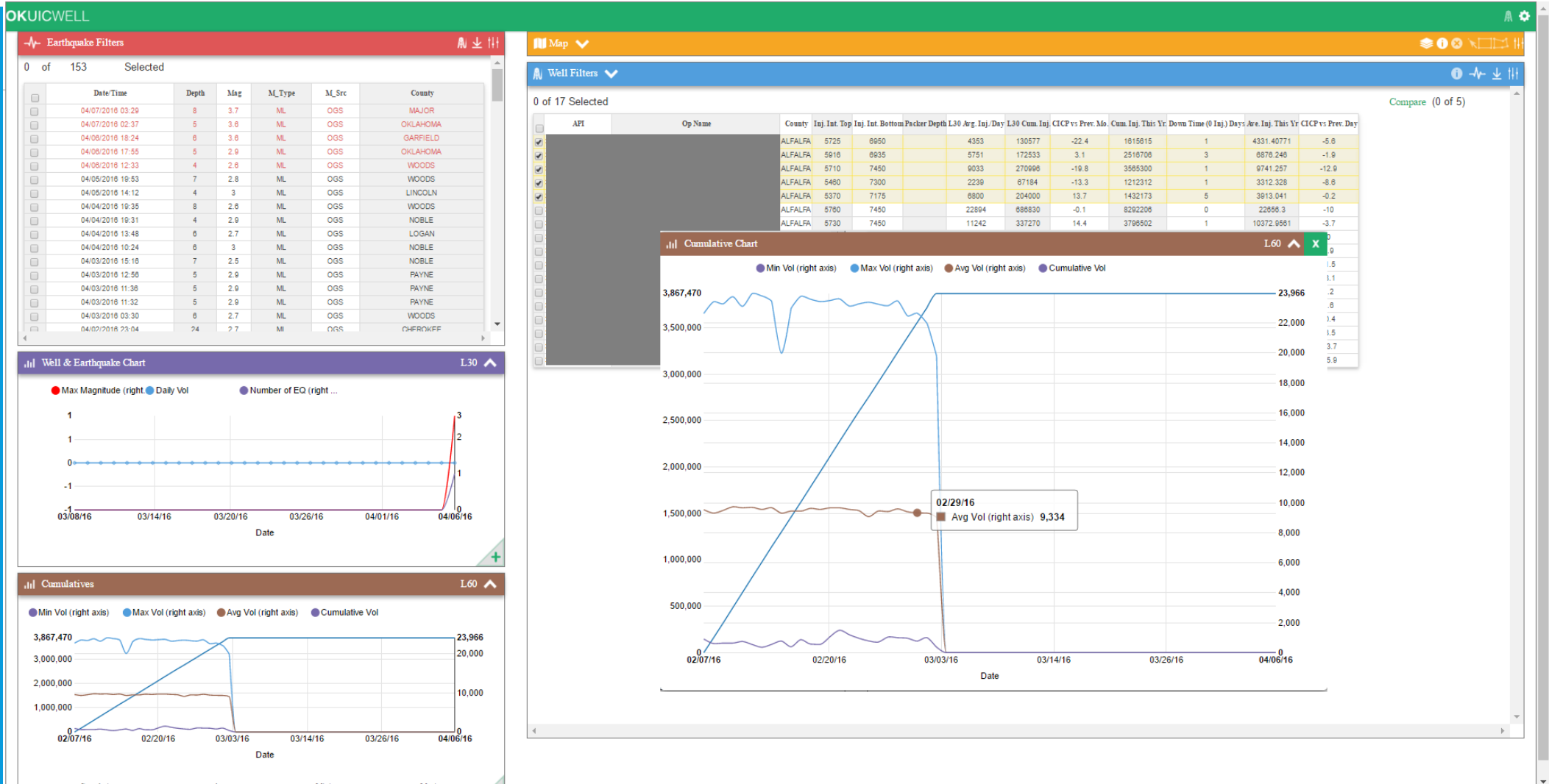
Well & Earthquake Chart L30

Cumulatives L60

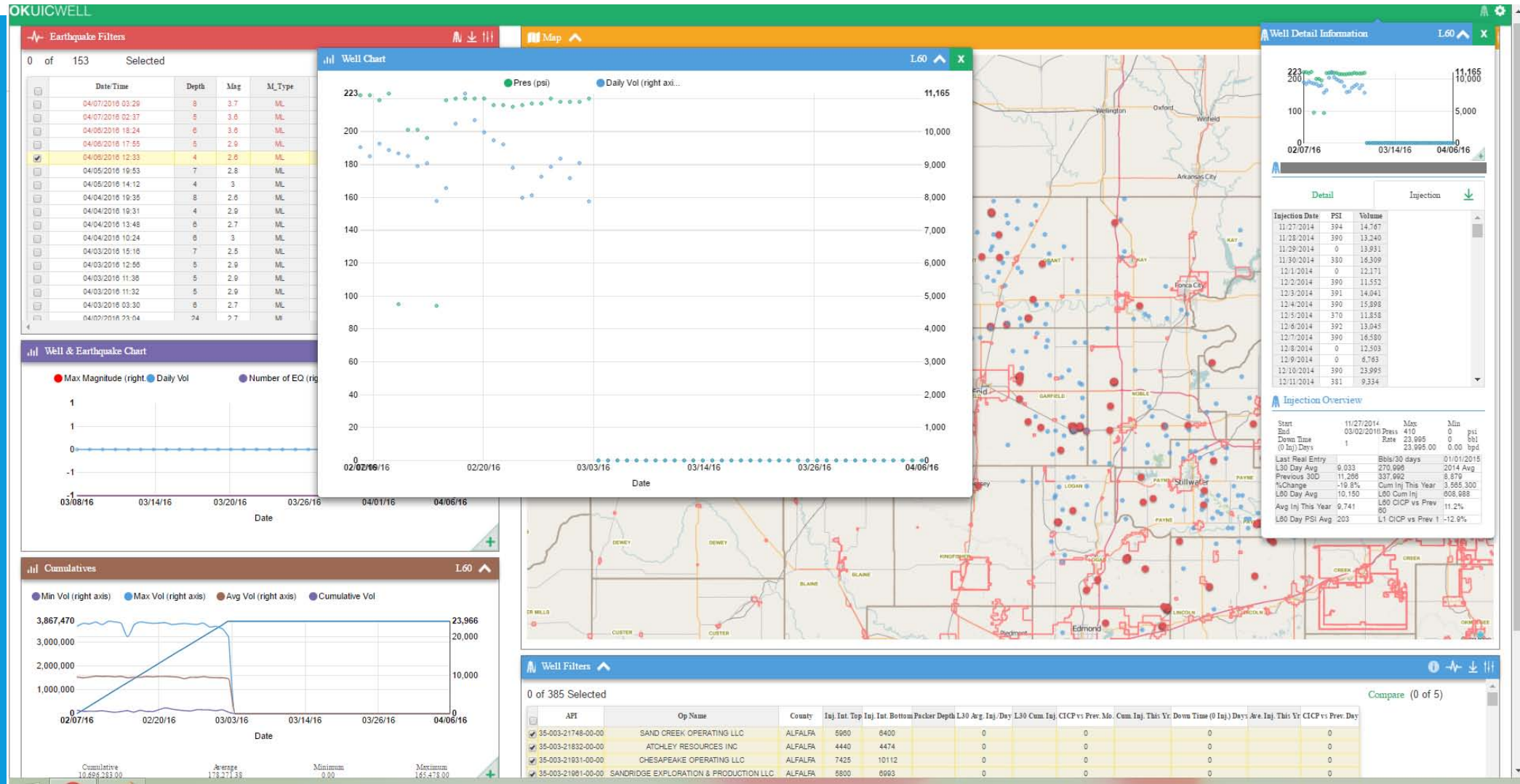
WELL CARDS AND LAYERS



INTERACTIVE CHARTS



ALTERNATE VIEWS AVAILABLE



DATA DOWNLOAD/EXPORT

The screenshot displays a software interface with three main components:

- Earthquake Filters:** A table showing 153 selected earthquakes with columns for Date/Time, Depth, Mag, M_Type, M_Src, and County.
- Well Filters:** A table showing 17 selected wells with columns for API, Op Name, County, and various production metrics.
- Excel Export:** An Excel spreadsheet titled 'well (18) - Excel' showing a detailed data table for well production and completion data.

Earthquake Filters Table:

Date/Time	Depth	Mag	M_Type	M_Src	County
04/07/2016 03:29	8	3.7	ML	OGS	MAJOR
04/07/2016 02:37	5	3.8	ML	OGS	OKLAHOMA
04/06/2016 18:24	6	3.6	ML	OGS	GARFIELD
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04/04/2016 13:48	6	2.7	ML	OGS	LOGAN
04/04/2016 10:24	6	3	ML	OGS	NOBLE
04/03/2016 15:16	7	2.5	ML	OGS	NOBLE
04/03/2016 12:56	5	2.9	ML	OGS	PAYNE
04/03/2016 11:36	5	2.9	ML	OGS	PAYNE
04/03/2016 11:32	5	2.9	ML	OGS	PAYNE
04/03/2016 03:30	6	2.7	ML	OGS	WOODS
04/02/2016 23:04	74				

Well Filters Table:

API	Op Name	County	Inj. Int. Top	Inj. Int. Bottom	Packer Depth	L30 Avg. Inj./Day	L30 Cum. Inj.	CICP vs. Prev. Mo.	Cum. Inj. This Yr.	Down Time (0 Inj) Days	Ave. Inj. This Yr.	CICP vs. Prev. Day
ALFALFA			5725	6950		4353	130577	-22.4	1615615	1	4331.40771	-5.6
ALFALFA			5916	6935		5751	172533	3.1	2516706	3	6876.248	-1.9
ALFALFA			5710	7450		9033	270996	-19.8	3565300	1	9741.257	-12.9
ALFALFA			5460	7300		2239	67184	-13.3	1212312	1	3312.328	-8.6
ALFALFA			5370	7175		6800	204000	13.7	1432173	5	3913.041	-0.2
ALFALFA			5760	7450		22894	868830	-0.1	8292206	0	22856.3	-10
ALFALFA			5730	7450		11242	337270	14.4	3796502	1	10372.9581	-3.7
ALFALFA			5505	7225		3649	109468	3.5	1318842	9	3603.39355	0
ALFALFA			5610	8900		17986	536560	4.4	8003888	1	21868.5499	2.9
ALFALFA			5735	7600		10239	307174	-12.2	3725951	1	10207.5168	-1.5
ALFALFA			6007	8395		958	28730	86.7	1002977	4	2740.37427	-8.1
ALFALFA			5725	7413		19215	579448	-0.1	8017585	1	21905.97	1.2
ALFALFA			6115	6983		18659	556780	13.5	7500553	1	20493.5879	3.6
ALFALFA			6473	7666		14356	430670	-11.1	4871983	2	13311.1016	-0.4

Excel Spreadsheet Data (Well 18):

API	Permit_Oi	Operator	Operator	Operator	Well Name	Legal Local	County	Latitude	Longitude	InjntTop	InjntBott	Formation	PackerDe	TubingSiz	DailyRepc	DailyRepc	Permitted	Permitted	LastRealEt	AvgDailyI	AvgDailyI	AvgDailyI	AvgDe
ALFALFA							ALFALFA			5725	6950			7	#####	3/2/2016	2000	100000	3/2/2016	4353	5607	4979.85	4331.
ALFALFA							ALFALFA			5916	6935			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	5751	5578	5664.65	6876.
ALFALFA							ALFALFA			5710	7450			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	9033	11266	10149.8	9741.
ALFALFA							ALFALFA			5460	7300			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	2239	2583	2411.3	3312.
ALFALFA							ALFALFA			5370	7175			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	6800	5980	6389.933	3913.
ALFALFA							ALFALFA			5760	7450			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	22894	22910	22902.15	226.
ALFALFA							ALFALFA			5730	7450			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	11242	9828	10535.1	1037.
ALFALFA							ALFALFA			5505	7225			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	3649	3527	3587.917	3603.
ALFALFA							ALFALFA			5610	8900			7	#####	3/2/2016	2000	80000	3/2/2016	17986	17227	17606.82	2186.
ALFALFA							ALFALFA			5735	7600			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	10239	11665	10952.17	1020.
ALFALFA							ALFALFA			6007	8395			5 1/2	#####	3/2/2016	2000	80000	3/2/2016	958	513	735.3333	2740.
ALFALFA							ALFALFA			5725	7413			7	#####	3/2/2016	2000	80000	3/2/2016	19215	19240	19227.28	2190.
ALFALFA							ALFALFA			6115	6983			7	#####	3/2/2016	2000	80000	3/2/2016	18659	16445	17552.02	2049.
ALFALFA							ALFALFA			6473	7666			4 1/2	#####	3/2/2016	2000	60000	3/2/2016	14356	16152	15254.02	133.

